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Systematic Evaluation and Analysis of Failures using AI

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benboudissa bilali

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ABBREVIATION

AMDEC	Analysis of failure modes, their effects and their criticality
GP2/Z	Name of the complex located in ARZEW
GL4/Z	Name of the complex located in ARZEW
CEA/Z	Name of the complex located in ARZEW
GP1/Z	Name of the complex located in ARZEW
GPL	Liquefied petroleum gas
TC	Turbocharger
BOG	Gas boil-off
DCS	Control room (Digital Control System)
HP	High pressure
MP	Medium pressure
BP	Low pressure
C_{3c}	Commercial propane
C_{4c}	Commercial butane
HSE	Health safety environment
QSSE	Quality health safety environment
OHSAS	Occupational health and safety assessment
ISO	International Organization for Standardization
APR	Preliminary risk analysis
HAZOP	HAZARD AND OPERABILITY STUDY (SAFETY STUDY ON FLUID CIRCULATION DIAGRAM)
LV	Level valve
PV	Pressure valve
P	Pressure
PIC	Regulator, pressure indicator
FIC	Regulator, flow indicator
CO	Carbon monoxide
C	carbon
O_2	Oxygen
NOx	Nitrogen oxides

AL	Alarm
SD	Shutdown
FCV	Flow regulating valve
CC	Combustion chamber
CO_2	Carbon dioxide
FMECA	Failure Modes, Effects and Criticality Analysis
P	Probability of occurrence index
G	Consequence Severity Index
C	Criticality
TCV	Temperature regulating valve
PCV	Pressure regulating valve
ΔP	Differential pressure
H_2	Hydrogen
GN	Natural gas
BS	Security fence
PPM	Part-per-million
GN	Natural gas
N_2	Nitrogen
SOx	Sulfur oxides
l’op 35	Programmable robot

Contents

Introduction:

In the ever-evolving landscape of industrial safety and risk management, the integration of advanced analytical techniques with cutting-edge artificial intelligence (AI) technologies has emerged as a pivotal strategy for enhancing the efficiency and accuracy of Health, Safety, and Environment (HSE) analyses. Traditional methodologies such as Failure Mode, Effects, and Criticality Analysis (FMECA) and Hazard and Operability Study (HAZOP) have long been the cornerstone of risk assessment within various sectors, including manufacturing, chemical processing, and oil and gas.
However, the advent of AI has opened new avenues for refining these processes, making them morerobust, dynamic, and responsive to the complexities of modern operations.

This thesis proposes the development and implementation of an AI-driven framework for HSE management, extending from an initial stage that involved creating an AI-Failure Mode, Effects, and Criticality Analysis (AI-FMECA) software site. This project aims to harness AI's capabilities to foster a more dynamic, predictive approach to HSE management, focusing on real-time risk assessment and incident prevention.

The innovation at the heart of this thesis is the integration of AI into the very fabric of HSE practices, transforming reactive systems into proactive safety nets that anticipate risks and mitigate them before they escalate into actual harm. AI technologies such as deep learning, predictive analytics, and automated decision-making systems will be utilized to analyze historical data and ongoing operations, thereby identifying potential risk factors and suggesting timely interventions.

This document outlines the conceptual framework for a pioneering web-based platform designed to blend HSE analyses with AI capabilities. The platform aims to streamline the risk assessment process,making it more accessible and user-friendly while leveraging the power of machine learning, data analytics, and predictive modeling to offer insights that are both comprehensive and forward- looking. By integrating AI into HSE analyses, the platform seeks to not only improve the identification and mitigation of potential hazards but also to predict and prevent future risks, thereby ensuring a safer and more sustainable operational environment.

The first section of this document provides an overview of the current state of HSE analyses, highlighting the challenges and limitations inherent in traditional approaches. It then introduces theconcept of AI integration, discussing the potential benefits and transformative impact it can have
on the field of risk management. The second section delves into the technical aspects of the proposedplatform, detailing the AI technologies and methodologies that will be employed to enhance the accuracy and efficiency of HSE analyses. This includes a comparison between the handiness application and site application, data processing techniques, and user interface design considerations that will make the platform intuitive and user-friendly.

The final section outlines the implementation strategy for the platform, including a discussion of the necessary resources, timeline, and stakeholder engagement. It also addresses the expected outcomes and benefits of the platform, both in terms of immediate improvements in risk management practicesand the long-term contribution to the evolution of HSE analyses within the industry. Through this innovative approach, the platform aims to set a new standard for HSE excellence, driving a culture ofcontinuous improvement and proactive risk management.

CHAPTER I:

Presentation of Complex GP2/Z

I. Presentation of Complex GP2/Z

I.1. INTRODUCTION:

The complex GP2/Z is Sonatrach, the national company charged with the transport, refining and marketing of hydrocarbons, which was established on 31 December 1963. Its organization is based on the activities of energy, national development and exploitation of hydrocarbon deposits.

The complex GP2/Z located in the north-west of the country to 42 km of Oran in the commune of Béthioua. The plant is designed to separate LPG propane and commercial butane.

Identification card du complex GP2/Z

LOCATION : Arzew

SIZE : 13.5 hectares

Objective : Treatment of 1.4 million tonnes of charge GPL.

Products : Propane and commercial butane.

Process : Distillation under pressure.

Number of trains : Two (02) trains semi-modular.

Manufacturer : JBC

Date of starting work : 1973

storage Capacity: Propane and commercial butane, two (02) storage containers Capacity 70 000 m^3 each.

HUMAN RESOURCES

Number of staff : 333 agents

Framework : 125 officers

Master : 177 officers

Runtime : 31 agents

I.2. HISTORY OF THE COMPLEX GP2/Z:

The complex GP2/Z has nearly thirty (30) years of existence. The construction project has been launched in the year one thousand nine hundred and seventy (1970) by the English company JBC.

Important dates to remember are :

- **1973**: commissioning of the complex designed to handle 4 million tons of a mixture ofcondensate / LPG.
- **1984**: the Judgment of the complex following the commissioning of the units of stabilizationof the condensate in the field of Hassi R'mel and Hassi Messaoud.
- **1990**: Restart the complex after the conversion of his process of reboiling for the treatmentof a capacity of 0.6 million tons per year.
- **1996**: Extension of the complex to treat a capacity of 1.2 million tons of LPG per year. Inaddition, modifications have been made, such as :
  - ✓ the conversion of two (02) columns of separation of condensate /LPGcolumns depropanization ;
  - ✓ the implementation of the reboilers column-level repurposed andadjustment of their control loops ;
  - ✓ the renovation of the cooling towers, and compressors in the system boil off ;
  - ✓ the construction of a new control room and replacement of instruments andpneumatic control system-DCS ;
  - ✓ renovation of gas turbines, the loading arm, air compressors, posts, electricalHT and MT ;
  - ✓ the implementation of a new unit of dehydration of the load.
- **1999** : Expansion of the processing capacity of the complex to process 1.8 million ton peryear. During this extension, a number of changes have been made, such as:
  - ✓ the replacement of the trays of the column separation of LPG by the platters,whose performance is superior ;
  - ✓ the installation of new balloons separators and heat exchangers, high-capacityat the level of the refrigeration zone ;
- the replacement of the circulation pumps of the fluid and of the charge pumpsof the GPL by pumps of larger capacity.
- **2000**: extension Project : the production capacity had to be carried to 2.5 million tons.

The scope of the project extension was to be limited to the following achievements :

- ✓ an additional unit of separation of LPG 160 T/ h ;
- ✓ the installation of a new refrigeration unit ;
- ✓ the increase of the capacity of the storage products refrigerated ;
- ✓ the extension of the electrical network low voltage ;
- ✓ the installation of a new furnace oil diesel oil ;
- ✓ a new unit of dehydration.

Due to an incident that occurred at the level of the word-compressor as of the date of the 24/07/2003, it was decided IHI/ITOCHU for the security and the reliability of the complex. This provider has made the following changes :

I.2.1. At the level of the storage section of the load LPG :

- ✓ Mounting a new sphere of storage buffer 420/6105G.
- ✓ Installation of new valves XV at the level of dehydration of the load to the GPL for thesequence of regeneration.

I.2.2. At the section level separation :

- ✓ Installation of new valves discharge motor-pumps GPL.
- ✓ Thermal insulation of the upper part of the two splitter A&B.
- ✓ Relocation of three motor-pumps of the charge GPL.
- ✓ Implementation of two new filters downstream of the dryer for the dehydration ofpropane commercial.
- ✓ Relocation of the four motor-pumps of reflux from the inside to the outside of the trainsof separation.

I.2.3. At the level of the refrigeration section :

- ✓ Installation of valves level VL to regulate the level of propane refrigerant of the threestages BP, MP, and HP.

I.2.4. At the level of the heating system oil TORADA TC :

- ✓ Mounting of the pump 425/6215E hot oil to power the circuit of the heat transfer fluid.
- ✓ Installation of a new oven 401/6201D for oil TORADA TC.

II DESCRIPTION OF THE PROCEDURE

The procedure see (FigureI.2) bellow includes three sections : separation, refrigeration and storage (Figure.I.1) to which must be added to the loop of the heat transfer fluid.

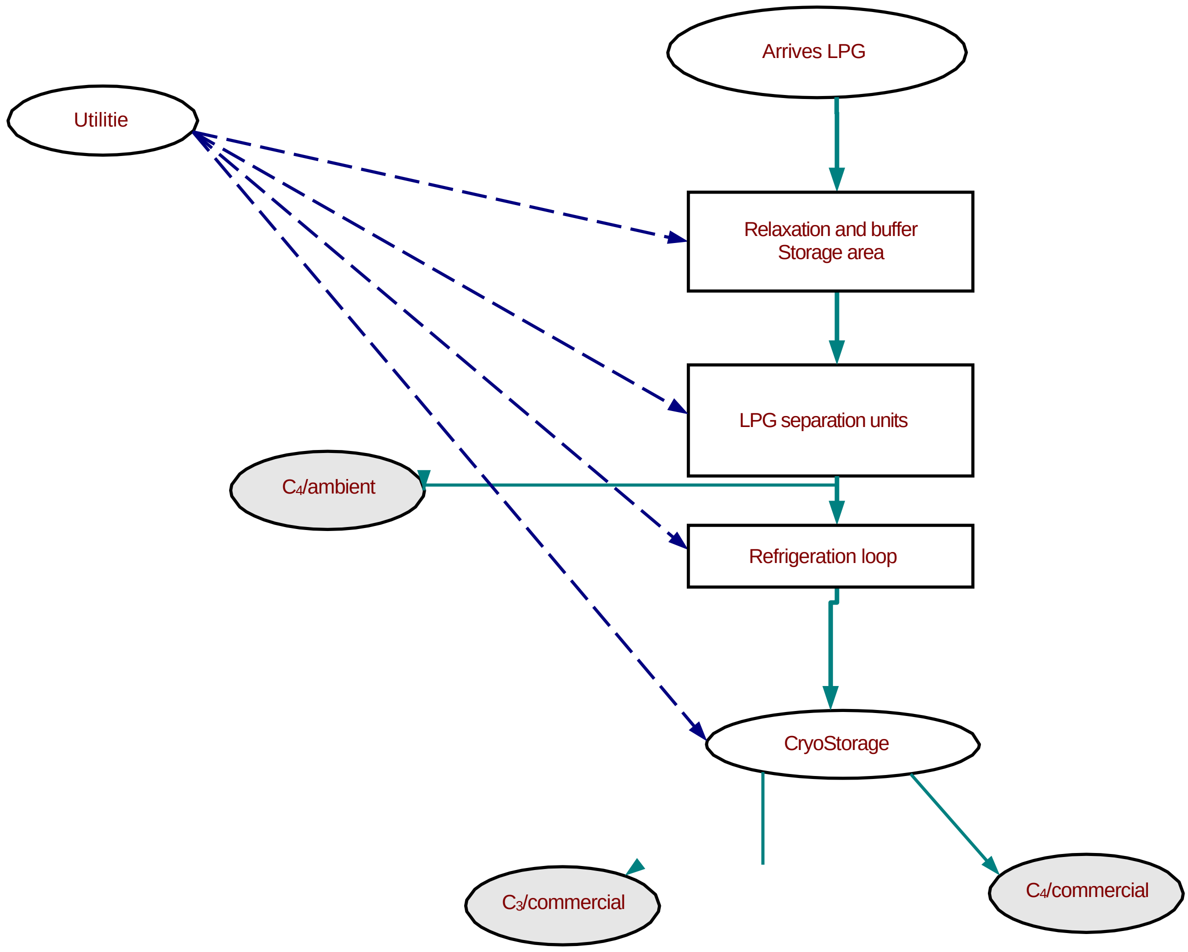


Figure.I.1: block Diagram of the complex GP2/Z

II. Section separation

II.1.1. - Storage buffer

The burden of LPG from the fields south of the Sahara, is received at the level of a relaxing resort (buffer storage). This section is to receive the GPL and store it in the spheres of charge before sending it to the section of dehydration, which is the next phase of processing. It consists of two spheres A/B with a capacity of 1 100 m^3 each, and 04 charge pumps A/ B/ C/ D. Each sphere features 02 valves : the valves are set at 16 bar for the sphere A and 11.2 bar for the sphere B. The LPG is stored at room temperature and at the pressure of 8 bar. In case of an increase of pressure, the valve opens to torch through the ball of fuel.

II.1.2. -Dehydration

The dehydration unit has been designed to dry the product and LPG up to a water content less than 1 ppm. This section is composed by the following equipment :

- II.1.2.1. a coalescing pre-power ;
- II.1.2.2. two dryers (adsorbers) A/B ;
- II.1.2.3. two filters LPG A/B ;
- II.1.2.4. a preheater gas regeneration ;
- II.1.2.5. a aero condenser gas regeneration ;
- II.1.2.6. a separator-gas regeneration.

Dehydration is to remove the free water and dissolved water and to prevent the formation of hydrates at the level of the equipment downstream. In fact, the process requires the lowering of the temperature below 0 °C, which excludes the presence of water in the facilities.

The product LPG, sucked up by the pumps, is routed under the control of flow rate to the coalescing pre-or the largest amount of the free water is removed from the load LPG by coalescence of water droplets in suspension through the filter elements and then separated by gravity. The water is permitted into the ball settling embedded in the bottom of the coalescing pre, then drained to the atmosphere under level control via the ball drain that serves to fan the entrained gas.

The adsorbers containing a bed of molecular sieve which is used for drying the GPL from the coalescing pre. The principle of dehydration can be done by adsorption of certain molecules (water molecules) and the rejection of larger molecules (molecules GPL). Water molecules are polar, they are strongly attracted to the molecular sieve ; however, the molecules of non-polar (lp) are free to the dryer. During the passage of the burden of LPG through the bed of molecular sieve, the water is adsorbed, then eliminated by the heat during the regeneration cycle (see Table.I.1).

Sequence	Time	Valves open
1. Drainage of the GPL	02 hours	For drainage Injection Fuel gas
2. Heating	8.5 hours	Input Fuel gas hot Output Fuel gas hot
3. Cooling	5.5 hours	Input Fuel cold gas Output Fuel gas cold
4. Fill	02 hours	Output Fuel gas to torch
5. Stand By	06 hours	No
Total	**24 hours**	

Table.I.1 : Mode of operation of the two absorbers**.**

II.1.3. - Separation

The separation unit has been designed to separate the mixture of the load LPG propane business as a product of the head of the column, and commercial butane as a product of the bottom of the column. It is made up of 02-trains (02 splitters) A/B, including the following equipment :

- ✓ a separation column 46-trays ;
- ✓ a preheater to load LPG ;
- ✓ a battery of air-cooled condensers ;
- ✓ a ball of reflux ;
- ✓ two pumps of the reflux ;
- ✓ a boiler ;
- ✓ three charge pumps ;

Before getting to the separation column, the load LPG is located at a pressure of 22.5 bar and passes through the preheater, where it is preheated by the butane from the bottom of the column dépropanization. The inlet temperature of LPG is regulated by the valve that is located on the output line of the butane in the bottom of the column, which by-pass the heater A : the higher the GPL is cold and the valve will tend to close for a maximum of butane hot to pass through the preheater Has and vice versa. The speed input of the GPL is itself controlled by an indicator of flow control.

The current GPL from the preheater Has between in the column at the level of the feed tray, n°24. The light hydrocarbon is separated from the power supply and rise to the top of the column against the current of a reflux continued for propane. Commercial propane extracted as a by-product of head of distillation is condensed in full at the level of the air-cooled condensers. The pressure head of the column is controlled by the two valves that are located upstream of the air-cooled condensers. When the pressure of the head of the column increases, the valve opens and the other closes so that the propane passes through the air-cooled condensers and, conversely, when the pressure of the column head fall so that the propane by-pass by the air-cooled condensers. When the pressure cannot be regulated by the two valves, the pressure controller opens up to the network of torch. The column also has two valves set at 22.5 bar, which flow to torch in case of overpressure excessive. The ball reflux is also equipped with a pressure relief valve calibrated at a pressure of 22.5 bar.

The propane from the ball of reflux is sucked by a pump reflux A/B. A part is reintroduced in the head of the column as reflux in the column. The flow rate of reflux is controlled by the indicator of flow control. The other part of propane will flow to the refrigeration via the control valve to the level that will maintain a liquid level in the flask to reflux.

The liquid from the bottom of column (butane) enters into the boiler, where it vaporizes partially. The party sprayed returns to the column below the 46th plateau (the last) as rebouillage steam while the other part of the butane flows to the cooling via the control valve to the level that will maintain a liquid level in the boiler. This is what butane product in the bottom of the column, which allows you to preheat the GPL from the side grille in the preheaterA.

II.1.4. -Section refrigeration

a) Refrigeration products

Section refrigeration is to cool down the products propane and butanes trade to their storage temperatures respective or - 45 °C for propane and

- 15 °C for butane at atmospheric pressure. The refrigeration system is a cascade system that uses propane, pure as a refrigerant. The cooling is done using a closed-loop three-level temperature is 11.8/ - 16,9 and - 40,3 °C, corresponding to the high pressure (6 bar), medium (1,8 bar) and low (0.5 bar).

b) Circuit propane commercial

Commercial propane from two balls of reflux Was for the train and the B train B is routedunder level control to the machine, and then it enters in the cooler (chiller) from the floor of HPat a temperature of 40 °C and exits at a temperature of 14.3 °C. the output of the chiller, the product passes through the dehydration of guard designed for the drying of the propane business. The content must be less than 1 ppm at the exit of dehydration in order to avoid the formation of hydrates (because of closures) and then the product goes to the floor to the MP through a 2nd chiller, where it exits at a temperature of -14,6°C. The propane commercial thengoes to the floor BP refrigeration through a 3rd chiller where it exits at a temperature of - 37,7 °C.

The refrigerated product, then goes through the ball flash (ball detent) that is not the current case where it is expanded to 0.4 bar to reach the temperature of -45 °C which is the temperature of storage of the finished product at the tray for storage of the propane refrigeration. The product is finally dispatched to the storage bin by means of a pump.

c) Circuit of the commercial butane

The commercial butane at the bottom of the two columns of dépropanisation is routed under level control to the machine. He then was at the level of the floor, the HP of the chiller at a temperature of 40 °C and exits at a temperature of 14.6 °C. The product is admitted then to the floor BP at the level of the chiller where it exits at a temperature of -11 °C and then it is conveyed to the storage bin of butane where a temperature of -15 °C.

Butane ambient, meanwhile, is obtained by sending a portion of the proceeds out of the cooling system to the spheres of butane ambient. The spheres of butane ambient is maintained at a pressure of 8 bar in the middle of the pressure valve which is part of the circuit fuel gas.

The commercial butane at the exit of the cooling system will be sent to the spheres of butane ambient which allows the filling of the past.

d) Loop refrigeration propane

The propane pure is stored in the ball of propane refrigerant to a pressure of about 16 bars and at a temperature of around 40 °C. The balloon is equipped with two safety valves set at a pressure of 18.2 bars. The ball feeds sub level control of two chillers high-pressure side grille.

The refrigerant then passes through the valve level control (1) to feed the side grille of the chiller (A) and the valve (2) to feed the side grille of the chiller (b). The relaxation takes place downstream of the two control valves level so that the propane pure between, respectively, in the two chillers at a pressure of 6 bar and a temperature of 11.8 °C.

The same-level control system is used at the level of the medium and the low pressure. The chiller (A) supplies power to the chiller on the 2nd floor of cooling of the propane business, and the chiller (B) supplies power to the chiller of the 2nd and last floor of cooling of commercial butane. After relaxing the propane pure between, respectively, in the chillers (A) and (B) at a pressure of 1.8 bar and a temperature of -16,9 °C. Each chiller is equipped with a safety valve.

At the level of the 3rd floor of refrigeration (BP), there are only commercial propane, which is cooled, the butane having completed its refrigeration cycle.

On each floor, the fumes from chillers are taken over by a turbocharger via balloons separators which allow for the removal of all liquid droplets entrained with the vapor propane.

They are compressed in the centrifugal compressor stage driven by a gas turbine and returned to the air-cooled condensers A/B to be condensed and then returned the ball to perform a new cycle.

III. Section storage

This section is used for the storage of propane and commercial butane refrigerated. It includes two trays, each one is 70 000 cubic meters of capacity. A storage bin propane (420/6204) and a storage bin of butane (420/6205), but also two spheres with a capacity 1115m^3 each for the storage of butane ambient .

Commercial propane (C3C) arrives from the ball 410/6102 of the loop BOG. The tray has two rows, one for the nitrogen that is used for inerting in the case of a work, and the other for the fuel gas, which displaces nitrogen after use and maintains a positive pressure in the tank. Four pump (425/6104A-B-C-D) are immersed in the tray in order to ensure the shipment of propane to the loading docks on the role of the pump 425/4104D is to chill the line for the shipment of propane commercial cold temperature of -40°C to -47°C.

The storage bin of butane is identical to that of propane, with the same number of submersible pumps (425/6101A-B-C-D), except that storage temperature is higher than that of propane (between -10°C and -15°C).

Butane ambient of the same composition as the commercial butane, is stored in the spheres 420/6501E-F, which have a capacity of 1115m^3.the butane is extracted then the aero condenser 405/6214.it is stored at ambient temperature but at a pressure greater than atmospheric pressure ranging between 7 and 8.5 bar.

Two separate systems, "BOG" (gas evaporation the boil off gas) exist for the recovery of vapors from storage tanks propane/butane.

The vapors from the storage bin propane 420/6104 and the gas coming from the ball of relaxation propane products are compressed to 0.7 mpa s eff. At the level of the two centrifugal compressors (430/6101E/D), partially liquefied in the chillers 405/6107.

The liquid propane obtained passes through the separator 410/6105, a party shall return to the control level in the tank propane, the other part is sent to the heater load dééthaniseur in the section of de-ethanisation, and the steam is recovered as a gas release.

The liquefied propane containing C1 and C2 is pumped and sent to the section of de-ethanisation to eliminate C1 and C2 as a fuel gas and retrieve the product propane.

The liquid propane is then sent via the submersible pumps to the loading arms for the expedition.

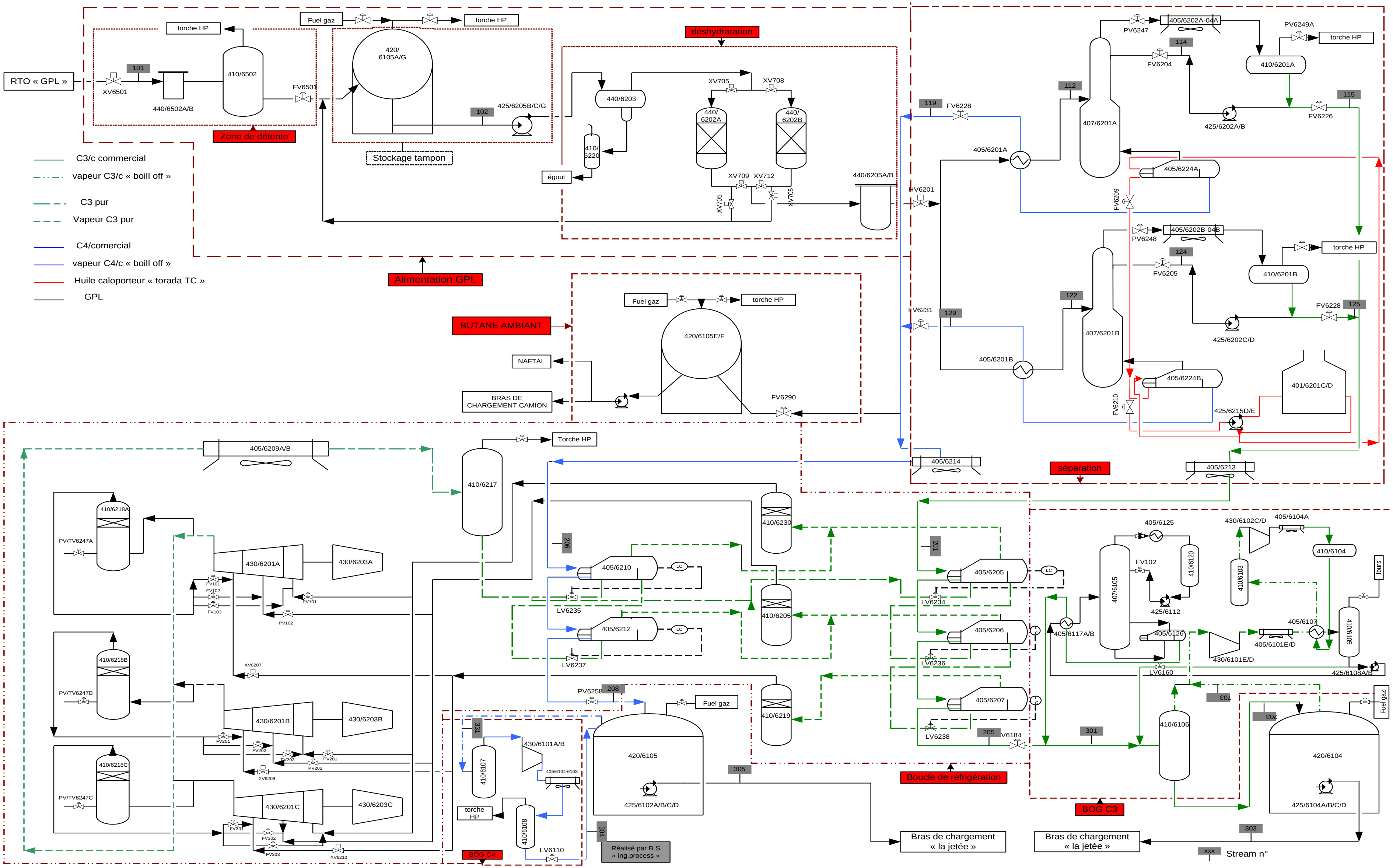
Similarly, the vapors of C4 from the storage bin 420/6105 are compressed by the compressors BOG (YORK) 430/6101A a/B and fully condensed at the condenser (405/6103). The butane liquid thus obtained passes through a separator 410/6108 and returned to control at the level of bac butane (420/6105).

- **Bin/ propane**

This reservoir ensures the storage of propane at atmospheric pressure and at a temperature of -45 °C. The tank is equipped with three safety valves set at different levels of pressure, respectively, 1010, 1030 and 1060 mm H_2O.

- **Tray butane**

This capability is intended to ensure the storage of butane at atmospheric pressure and at a temperature of - 15°C. The tank is equipped with three safety valves set at different levels of pressure, respectively, 1010, 1030 and 1060 mm H_2O .



FigureI.2 represents the general scheme of the procedure used in the complex GP2/Z

CHAPTER II:

FMEAC

II. Total Quality, prevention and FMEAC

A company's existence is based on the interrelationships between its staff and customers on the one hand, and its shareholders, management and staff on the other. All these interrelationships are governed by a *business process* that also interacts with external partners, both upstream and downstream. The strategy that aims to satisfy all these parties simultaneously is *totalquality*. Simple to define, complex to achieve.

The business process consists of a set of systems that must be perfectly organized and integrated. A system is made up of several processes, a process of several procedures, a procedureof several activities and tasks. If we can identify everything that could go wrong in the systems, and if we can eliminate the probable causes of any failures that may occur, then all the systems willoperate correctly, without conflict, without stoppage, with total quality in mind. This logic leads usto act *a priori* and not *posteriori,* as was done in the past and as some still do. Hence the importanceand necessity of a preventive approach to achieving total quality.

Approaches such as product inspection and control, as well as statistical process control, are insufficient to solve, prevent and avoid problems that may subsequently appear in a company'svarious business process systems. Among the tools and techniques for *preventing* potentialproblems, the FMECA method is a simple and highly effective one. FMECA stands for Failure Mode and Effect Analysis. The aim of this technique is to study, identify, prevent or at least reducethe risk of failure of a system, process or product.

The French Association for Standardization (Afnor) defines FMECA as "an inductive method for performing a qualitative and quantitative analysis of a system's reliability or safety"[1]. The method consists in methodically examining potential system failures (*failure mode analysis),* their causes and their consequences on the operation of the whole system *(effects).* Once potentialfailures have been prioritized, *based on an assessment of the level of failure risk (criticality),* priority actions are initiated and monitored.

II.2. History and fields of application

FMECA was first developed in the USA by Mc Donnelly Douglas in 1966[2]. It consisted inlisting the components of a product and accumulating information on failure modes, their frequency and consequences. The method was developed by NASA and the armaments industry under the name FMEAC to evaluate the efficiency of a system. In a specific context, this method is a reliability tool. It is used for systems where reliability and safety objectives must be met. In the late 1970s, the method was widely adopted by Toyota, Nissan, Ford, BMW, Peugeot, Volvo, Chrysler and other major automakers.

The method has proved its worth in the following industries: space, armaments, mechanics,electronics, electrical engineering, automotive, nuclear, aeronautics, chemicals, IT and, more recently, services. In the IT field, the Software Error Effects Analysis (SEEA) method has been developed[3]. This approach is a transcription of FMECA into a software environment. Today, in a broader context such as total quality, prevention is not limited to manufacturing. It is now possibleto anticipate problems in all systems of the business process

and to seek preventive solutions a priori. This is why the application of FMECA in the various systems of the business process is souseful,
Often indispensable. This method is therefore considered a total quality tool.

It's important to note that the method is used in conjunction with other quality tools, and this combination considerably increases the method's capacity and effectiveness (some examples are mentioned below).

II.3. FMECA types and definitions

II.3 - Types

There are several types of FMECA, the most important of which are:

- *Organization* FMECA applies to the different levels of the business process: from the first level, which encompasses the management system, the information system, the production system, the personnel system, the marketing system and the finance system, to the last level, such as the organization of a work task.
- *Product* FMEAC or *Project* FMEAC is used to study the *design* phase of a product or project in detail. If the product comprises several components, we apply Component FMECA.
- Process *FMEAC* applies to manufacturing processes. It is used to analyze and assess the *criticality* of all potential product failures generated by the process. It can also be used for workstations[4].
- The *FMECA-average* applies to machines, tools, measuring equipment and devices, software and internal transport systems.
- Service *FMECA* is used to check that the value added by the service corresponds to customerexpectations, and that the service realization process does not generate failures[5].
- Safety *FMEAC is* applied to ensure the safety of operators in processes where there is a risk tothem.

II.4. - Definitions of failure mode, failure cause and failure effect

Failure simply means that a product, component or assembly:

- Does not work;
- Does not work when expected;
- Does not stop when expected;
- Operates at an undesired time;
- Works, but the required performance is not achieved

Failure mode is the way in which a product, component, assembly, process or organizationfails or deviates from specifications. Here are a few examples to illustrate this definition:

- Deformation;
- Vibration;
- Wedging;

- Loosening;
- Corrosion;
- Leak;
- Loss of performance;
- Short circuit;
- Blazing;
- Don't stop;
- Does not start;
- Exceeds tolerated upper limit, etc.

A *cause of failure* is obviously what leads to a failure. We define and describe the causes of each failure mode considered possible, so that we can estimate its probability, detect its secondary effects and plan corrective actions to rectify it. The *effects of a failure* are the local effects on the system element under study, and the effects of the failure on the end user of the product or service.

II.5. - Two aspects of the method:

- **Qualitative and quantitative aspects.**
  - ✓ The qualitative aspect of the study consists of identifying potential failures in the functionsof the system under study, researching and identifying the causes of failures, and determining the effects which may affect customers, users and the internal or external environment.
  - ✓ The quantitative aspect consists in estimating the risk associated with the potential failure.The aim of this estimation is to identify and prioritize potential failures. These are then highlighted byapplying certain criteria, including the impact on the customer. Ranking failure modes in descending order makes it easier to identify and take priority action to reduce the impact on customers, or to eliminate the causes of potential defects altogether.

III. Method steps

The method is based on an eight-step process (Figure.II.1). As with many approaches, there is a preparatory phase consisting of collecting data for the study, setting up a working group and preparing files, tables and software.

III.1. Setting up a working group

The multi-disciplinary team responsible for carrying out the study is formed. The people involved in a FMEAC-process study, for example, represent the departments of research and development, purchasing, marketing, maintenance, quality, methods and manufacturing. The presence of a well-trained facilitator in specific techniques of the approach and teamwork is a prerequisite for successful application of the method.

Garrett Automotive Ltd (GAL) provides an interesting example of how a product FMEACteam can be set up. The company has been recognized as one of Ford's top suppliers, and has wonthe UK's Queens Awards for Export. The company has set up a total quality teaching program (Teach-in Company Programme[6]) which includes the FMECA method. At Garrett, FMECA team members come from a variety of departments.

The product engineer is responsible for preparing the FMECA. Before the team meeting, he or she prepares the first six columns of the FMECA table (see *Table.II.1*): each part number, its function, potential failure modes, possible causes, potential effects, current design checks. At the start of the meeting, the team analyzes each element of the document to ensure that nothing is missing. The other team members are:

The sales representative is the interface between the company and the customer. He provides the team with the necessary information on the customer's needs and expectations.

The quality department representative, who acts as a facilitator or coordinator and acts as a link between all stages of the method. He helps to identify potential design failures during theproduction process.

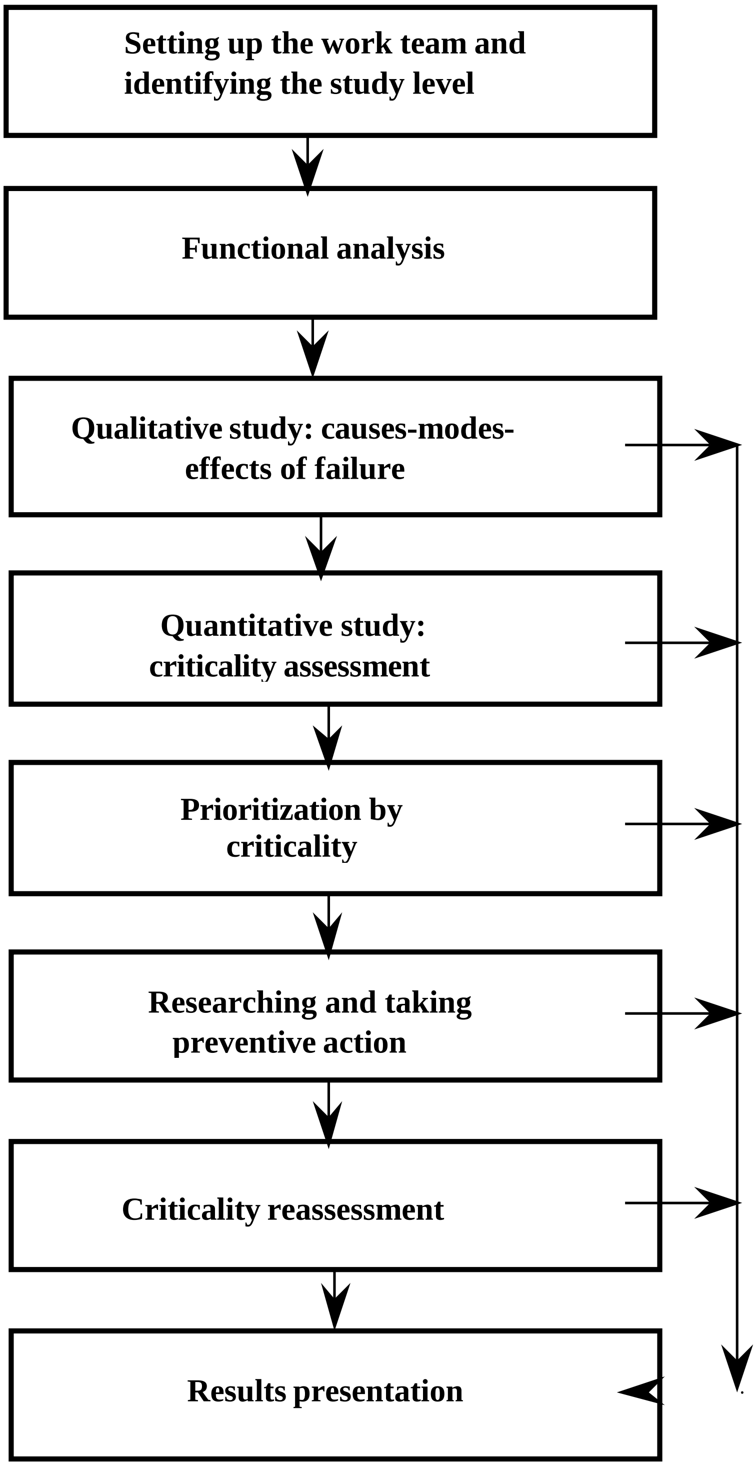


Figure.II.1 - The FMECA approach

The Manufacturing Engineer is a very influential member of the team, particularly in thedevelopment of design and manufacturing processes.

Designers are sometimes asked to take part in team meetings, in order to provide more details on design and design changes, or to learn about the history of the product.

This configuration of team members is similar to that of the FMECA-process, and is binomen's definitive. It is important to note, however, that larger teams (with more than seven participants) are less effective than smaller ones (with between four and six participants). The key to the FMECA team's success lies in the total commitment of its members and the interaction between them[7].

System :									
Subsystem :									
The element	Function	Failure Mode	Causes	Effects	Detection	Frequency	Gravity	criticality	Actions recommended

Table.II.1 Example of FMECA table

Product/process FMECA

Product function or process Operation	Potential failure **mode**	**Effect** of failure	Possible **causes of** failure	Evaluation				Preventive action	Results				
				Detection	Frequenc	Gravity	RPN	Recommended	Socke				

Table.II.2 Product/process FMECA

III.2. - Functional analysis

A failure is the disappearance or degradation of a function. So, to find potential failures,you need to know what the functions are.

The aim of *functional analysis* is to determine a product's main functions, constrained functionsand elementary functions.

- *The main functions* are those for which the system has been designed, i.e. to satisfy the user'sneeds.
- *Constrained functions* respond to interrelations with the external environment.
- *Elementary functions* ensure the main functions, i.e. the functions of the system's variouselementary components.

To carry out a functional analysis correctly, you need to perform three main steps:

1. Define the need to be met. The principle is to describe the need and how it is satisfied, and howit may not be satisfied.
2. Define the functions that correspond to the need. Each function answers the question: "**What's it for?** The answer must include **a subject and a verb** (e.g.: a razor shaves, a knife cuts). Wecan then determine the potential failure (the razor doesn't shave; the knife doesn't always cut).
3. Draw up a function tree to visualize the functional analysis. Main functions often include sub-functions, or result from a set of elementary functions. Hence the need for a function tree.

This is a block-diagram representation, constructed by defining the functions from level A the main functions up to level Z - the elementary functions of the components. All levels follow the same logic: receive a function - transform the function - transmit a new function (see figure.II.2)[8]

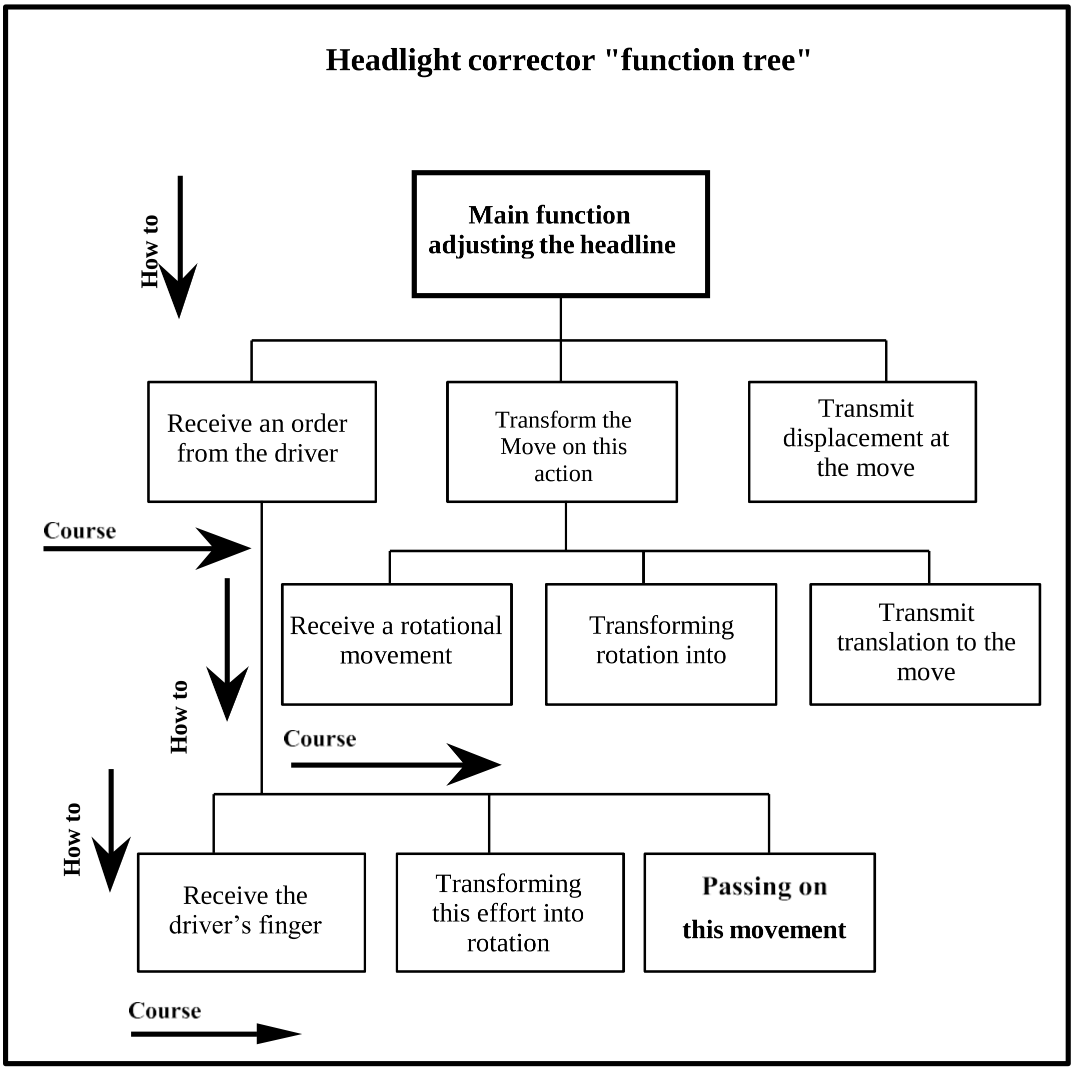


Figure.II.2-From "Methods and tools for total quality", by P. Lyonnet, Technical and Documentation Edition, 2nd Edition, page 74"

According to the American military standard for FMECA, a system (complex product) can be broken down into three levels: system, subsystems, component. These terms apply to both material and functional decomposition[9]. In short, the system is broken down into several levels of tree structure. The top level is the system, the bottom level is the component. Functional analysis is the key to establishing the best tree structure.

Possible for a system. The FMECA will then be carried out from the component level upwards to the various levels of the tree (*Bottom-up* approach)[10].

For a process, functional decomposition is into processes. For a process, decomposition isinto operations or activities, and for operations, decomposition is into tasks. An excellent means ofachieving functional decomposition is the process flow chart. Figure.II.3 illustrates a flow chart of acoffee dispenser process. This process is a set of elementary operations which take place from theneed to be satisfied to the consumption of Stator block. Once the functions have been identified, we move on to the analysis or qualitative study stage.

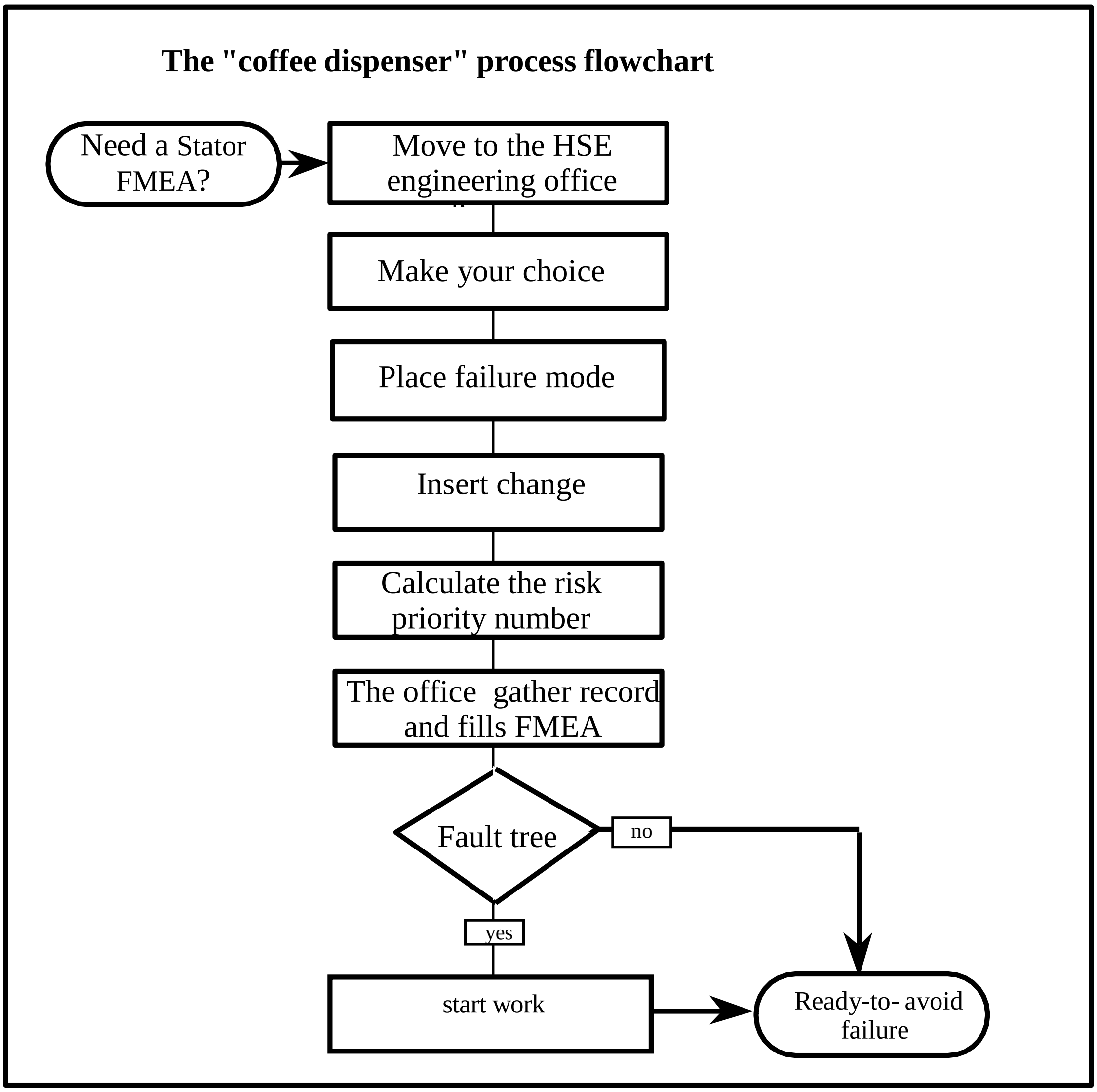


Figure.II.3 - The "Stator block" process flowchart

III.3. - Qualitative study of failures

This consists in identifying all possible failures, determining the failure modes, identifyingthe effects related to each failure mode, analyzing and finding the possible causes and the most probable causes of potential failures. To achieve this objective, functional analysis is used. Based on the functions defined, we seek Directly to potential failures (see Table.II.2). In this way, functional analysis helps to find the upstream *causes* and downstream *effects* of each failure mode.

Let's take the "place failure mode" operation in Stator block dispenser process. The operation is carried out correctly if the frailer is been with stator of the desired quality and volume.One failure mode is that the stator does not start correctly. A second failure mode is that the stator is slow. A third failure mode is that Stator block effect other element. Based on these three failure modes, we analyze the potential effect (probably negative) for the customer. The study is complete if we identifies the possible causes.

Each mode may have one or more causes. For the second failure mode, a possible cause isthat the machine lacks

Stator. A second possible cause is that there is a blockage in the machine's internal circuit preventing the Gear and Bereans from Working (see table.II.3).

The aim of the FMECA is to highlight critical points, in order to eliminate them and plan preventive measures. These points are highlighted according to certain criteria in a quantitative analysis.

III.4. - Quantitative study

It is an estimate of the *criticality index* of the *cause-mode-effect* trio of the potential failureunder study, based on certain criteria. Several criteria can be used to determine this index. In practice, a failure is often considered more important if:

- The consequences are serious;
- It often occurs;
- It happens, and there's a risk that it won't be detected.
- In practice, three scores - each on a scale of 1 to 10 - are assigned to each cause-mode-effect trio:
- **Gr**ating **-** *severity of effect* - consequences for the customer/user
- **O**rating **-** *probability of occurrence* - frequency of occurrence
- **D** rating **-** *probability of non-detection* - risk of non-detection

The criticality index (**C**) is obtained by multiplying the three previous scores: severity, probability of occurrence and probability of non-detection:

$$\mathbf{C = G \times O \times D}$$

Table.II.4 shows an estimate of the criticality index of the failure modes-causes-effects in the "coffee dispenser" process. If the machine fills the glass with hot water only, the customer will bevery dissatisfied. We therefore estimate a severity score of 10. The cause "Lack of coffee in the dispenser" can happen often, so for the probability of occurrence we estimatea score of 5. Detection is made by the maintenance worker when he comes to refill the machine with ground coffee; so, for the probability of non-detection we also estimate a score of 5. The threescores multiplied together give us the criticality index, which in this case is 250.

The word criticality corresponds to the English term *Risk Priority Numbers*[11].

III.5. - Prioritization

The main difficulty of a study designed to anticipate problems and seek preventive solutions stems from the very wide variety of potential problems to be considered. Hence the need for a hierarchy, to classify failure modes and organize their treatment in order of importance.

III.6. FMEAC process

Process operation	Potential failure mode	Failure effect	Cause possible failure	Evaluation				Preventive action recommended **plugs**	Results				
Visit distributor coffee fills the glass	Stator block doesn't start correctly or take start action	Dissatisfyed customer	A crack in the center	2	5	6	**60**						
			Lack of Lubrication	7	0	6	**0**						
	blockage in the machine's internal circuit	Very dissatisfied customer	Lack of position in the compressor	5	5	10	**250**						
			Blockage in stator	10	1	10	**100**						
	Stator block effect other element	Dissatisfyed customer	touch in element	7	1	8	**56**						
			• stator quality	1	10	8	**80**						

Table.II.4 criticality index of coffee dispenser

Prioritization according to the criticality scale enables you to decide on priority actions. In effect, it's a list of critical items or processes. They are ranked in descending order, generally in four categories (C>100; 100>C>50; 50>C>20; 20>C). This classification enables preventive actions to be modulated, their priority varying according to the category. Companies very often use a *criticality threshold* of 100[12] for product/process FMECA, and 16[13] for average FMECA.

III.7. - The search for preventive/corrective actions

Once the various potential failure modes have been ranked according to criticality indexes, the group designates those responsible for identifying preventive or corrective actions. Tools such as cause-effect diagrams, Pareto analysis, brainstorming and teamwork must be applied to ensure effective research. In practice, the working group focuses on reducing the criticality index through actions aimed at:

- Reducing the probability of occurrence (e.g. by modifying product or process design)
- Reducing the probability of non-detection (e.g. by modifying the process design or the control system)
- Reducing the severity of the failure effect (e.g. by modifying the design)

III.8. - Follow-up of actions taken and criticality reassessment

This is the moment of truth for the method. A new criticality index is calculated in the same way as for the first evaluation, taking into account the actions taken. This value of the new criticality index is sometimes referred to as the *residual risk*, and can be illustrated in the form of a Pareto diagram (Figure.II.4).

The aim of this reassessment is to determine the impact and effectiveness of the actions taken. The new criticality index must therefore be below the criticality threshold. Table.II.5 illustrates such a reassessment, showing that thanks to the actions taken, the new criticality indices are below a criticality threshold equal to 50.

III.9. - Results presentation

To be able to carry out and apply the FMECA, companies use tables designed specifically for the system under study and prepared according to the objectives sought. These tables are usually arranged in columnar form, and generally contain the information required to carry out the study. Tables.II.1 to 4 illustrate how to carry out a process FMEAC.

III. FMEAC and other total quality tools.

I. - FMECA and the Cause Tree (FTA)

FMECA is a tool for studying the consequences of *potential* failures, each taken individually, which is an inductive logic.

The Cause Tree Failure Analysis method[14] is a method which, starting from a given event, aims toidentify all its causes in order of importance, from the main causes to the most elementary ones. It's a graphic representation of an analytical approach, following a deductive logic. In short, the starting point is the *observed* failure, and the focus is on finding the causes. Unlike FMECA, this is a corrective approach. The two methods complement each other perfectly. When developing a new As a product, a cause-tree failure analysis carried out on an old product can be very useful.

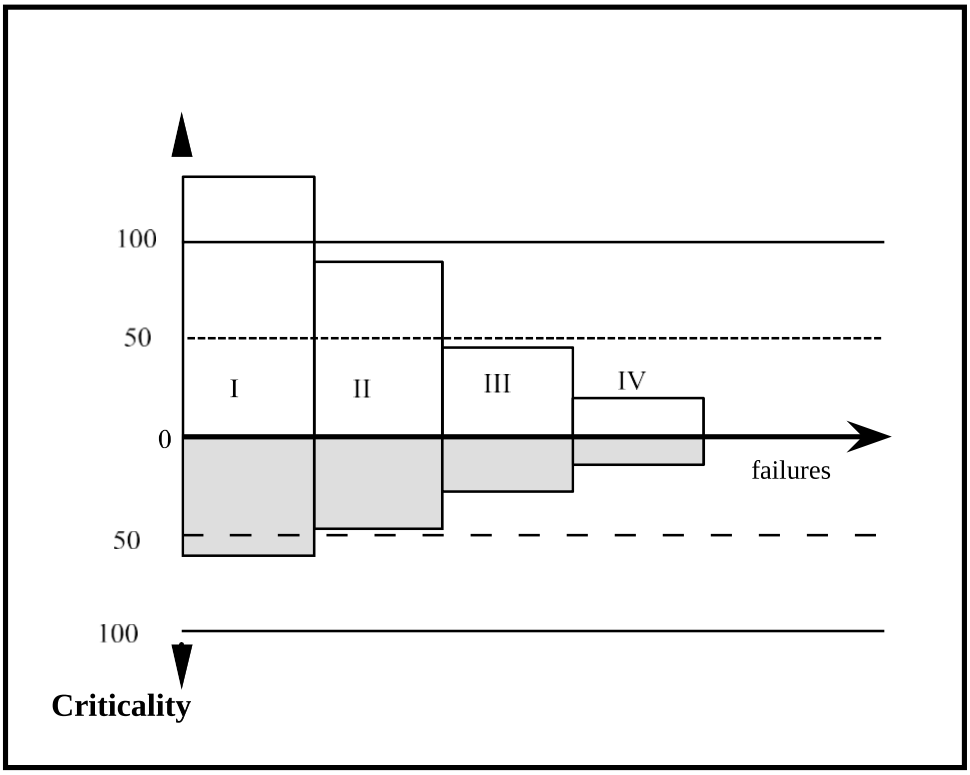


Figure.II.4 Pareto diagram of residual risk

I.1. - FMEAC and Quality Function Deployment

Quality Function Deployment (QFD) consists of cascading customer requirements throughall phases of new product development. FMECA can be perfectly integrated into the DFQ approach. Right from the design stage, the characteristics identified as critical by FMECA are monitored throughout the development and industrialization phases, right up to shipment. This approach is successfully used in Toyota factories and at Komatsu in Japan, and is sometimes referred to as reliability deployment[15]. In North America, FORD uses the same approach.

I.2. - FMECA and Statistical Process Control (SPC)

FMECA helps determine the characteristics to be monitored using statistical methods. If itis impossible to lock in the probable causes of any failures that may occur, statistical process control is implemented. Several companies in the automotive sector have implemented SPC following *FMECA-process* for characteristics with a criticality of over 100 and for characteristics with a severity rating of over 7 (scale from 1 to 10).

This approach is an excellent example of a preventive FMEAC-PSC package, which would enablethe process to be brought under control. In addition, the preliminary calculation of the operationalcapacity of the process is used as a criterion for determining the probability score for non-detection.Statistical techniques are therefore very useful sources for carrying out the study.

I.3. FMEAC process

Process operation	Potential failure mode	Failure effect	Cause possible failure	Evaluation: Detection	Evaluation: Severity	Evaluation: Occurrence	Evaluation: RPN	Preventive action: recommended plugs	Preventive action	Results: Detection	Results: Severity	Results: Occurrence	Results: RPN
Visit distributor coffee fills the glass	Stator block doesn't start correctly or take start action	Dissatisfyed customer	A crack in the center	2	5	6	**60**	• statistical monitoring of breakdowns monthly verification of the stator • enter the telephone number for the interview on the stator	• check • register the telephone number of the maintenance agency	1	3	5	**15**
			Lack of Lubrication	7	0	6	**0**			2	2	1	**40**
	blockage in the machine's internal circuit	Very dissatisfied customer	Lack of position in the compressor	5	5	10	**250**	• each morning Grease the stator block	• each morning Grease the Stator block	2	1	10	**20**
			Blockage in stator	10	1	10	**100**	Do regularly preventive maintenance	• monthly preventive maintenance	1	1	5	**5**
	Stator block effect other element	Dissatisfyed customer	touch in element	7	1	8	**56**	• one check perday	• 1 check perday	1	1	8	**8**
			• stator quality	1	10	8	**80**	Select brands, and identify the metal life	• brand and metal life				

Table.II.5 the impact and effectiveness of the actions taken

I.4. - FMEAC and the error-proofing system (Poka-Yoké)

According to some Japanese specialists, no matter what statistical methods are used, they cannot prevent a fault from occurring in a human-machine system. Shingon offers Poka-Yoké (Japanese for "error-proofing") systems[16]. There are two types of error-proofing system, dependingon the control functions, i.e. servo functions and warning functions.

Servo functions are functions which, when faults occur, stop the machines or trigger blocking systems, thus avoiding the occurrence of serial faults.

Alert functions draw workers' attention to anomalies by triggering an audible signal or flashing lights. The implementation of such functions can result from an FMECA study. Once potential failures have been prioritized, priority actions must be taken to reduce or avoid any risk. In fact, a warning function such as locating, or a control function such as locking, are excellent examples of preventive actions in the context of an inductive FMECA study. To illustrate this, let's take the example of an intersection with traffic lights. The worst possible failure is for the lights to be green in both directions. The potential effect of this failure is catastrophic, costing oneor more human lives. The solution that completely eliminates this risk is the installation of an anti-error system that rules out such a situation. If a failure occurs, this system must immediately trigger

flashing amber lights to warn cars and pedestrians that the traffic lights are not working.

II. - FMEAC and simultaneous engineering

Simultaneous engineering involves integrating customer requirements in terms of quality, reliability and cost with purchasing, process design, product industrialization, maintenance and financial requirements during the product design phase.[17] This logic requires the active participation ofmarketing, engineering, production, finance, purchasing, after-sales service, etc., with the aim of eliminating failures as far upstream as possible, reducing development costs and product time-to- market.

Simultaneous simulation of multiple requirements, specifications, conditions and options, and their translation into cost, schedule and risk terms, is possible thanks to a whole range of new DFMA-type software[18]. These programs are based on a number of specific modules:

- CAD/CAM - computer-aided design and manufacturing - helps to increase part symmetry and reduce manufacturing costs by simplifying assembly processes;
- PCM - (Predictive Costa Modeling) for comparative analysis of overall costs and costs during each phase of product development;
- Modules for assessing return on investment;
- FMEAC application modules, to improve product reliability and maintainability, andidentify critical processes;
- Expert system modules to optimize the use of multiple resources and processes;
- General overview modules to identify and propose optimal use strategies.
- The FMECA method fits perfectly into the simultaneous engineering methodology.

Together with the other modules, the application of FMECA ensures that a new produce Operating efficiency, profitability, rapid development and improved process performance in production.

There are other prevention tools specific to different sectors of industry. Most of them are similar to FMECA, or complement it.

II 1. FMECA and ISO 9000 standards

With the globalization of markets, the economy and competition, one of the other tools for total quality is the famous ISO 9000 series of international standards. To date, over 60 countries have adopted these standards. The standards prescribe the *elements of quality systems* that must bemastered and assured. There are several models in the series of standards, and companies use different methods to implement them.

FMEAC-product helps to implement ISO 9001 in the area of design control. FMECA-Process helps implement ISO 9001 and ISO 9002 models in the process control section. FMEAC-Asset can be used in the control of measurement and test equipment. Service FMECA helps to implement the ISO 9004-2 standard for services in the service design process. The use of FMECA is recommended by ISO 9004 for design qualification and validation activities[19].

II2. Summary

FMECA is a prevention method that can be applied to an organization, a process, a means, a component or a product, with the aim of eliminating the causes of potential defects as far upstream as possible. It is a means of guarding against certain failures and studying their causes and consequences. The method classifies and prioritizes failures according to certain criteria (occurrence, detection, severity). The results of this analysis are priority actions designed to significantly reduce the risk of potential failures.

CHAPTER III:

Application of the FMECA approach to the BOG

III. Introduction

One of the fundamental conditions for the safety of an installation is that the components can withstand the specified operating conditions so as to ensure the containment of the hazardous products used. In-depth examination of the operating procedures therefore makes it possible to determine the potential consequences of deviations from normal operating conditions.

Analysis of accident data from the ARIA (Analysis, Research and Information on Accidents) and CSB (Chemical Safety Board) databases shows that around 33% of accidents are due to material defects, corresponding to unusual operation of equipment (rupture, breakdown, etc.), and around 11% of accidents are due to loss of process control.

In this chapter, we looked at the analysis and risk assessment of the various equipment and installations in the BOG Propane section. To do this, we applied the FMECA method to identify the various problems that could arise on their components.

Commercial propane is a refrigerated product, stored at a very low temperature of around -45°C. However, during storage, the movement of the product in the storage tank creates evaporation, resulting in a rise in pressure. For economic and safety reasons, these vapors are recovered, compressed and liquefied again in the BOG section.

III.1.1 Description of the facilities in the BOG PROPANE section

I.1 Propane expansion tank 410/6106[20]

The 410/6106 drum is a vertical cylindrical tank with a convex bottom and roof, approximately seven (7) meters high, three (3) meters in diameter and eight (8) millimeters thick, attached toa skirt approximately four (4) meters long, designed to receive propane from the refrigeration section. The tank is made of ASME SA 516 grade 60 carbon steel with the following chemical composition:

Table.III.1 - Chemical composition of ASME SA516 grade 60 carbon steel

C	**If**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Cu**	**Mo**	**Ti**	**Al**
0.18%	0.4 %	0.95 /1.5 %	0.015%	0.008%	0.3%	0.3%	0.3%	0.08%	0.03%	0.02%

According to this composition, ASME SA516 Gr 60 carbon steel is used for the manufacture of gas and steam pressure equipment for use at low temperatures.

Table.III.2 - Technical characteristics of the 410/6106 storage tank

Parameter	value	Unit
Pressure		
Service	0.004	MPaG
Design	0.18	MPaG
Temperature		
Service	- 43.8	°C
Design	- 45.5 / 38	°C
Dimension		
Height	7	M
Diameter	3	M
Thickness	8	Mm
Corrosion allowance	1.6	Mm
Volume	57	m3
Weight		
Vacuum	9000	Kg
In use	31000	Kg
Full of water	75000	Kg

III .1 Buffer tank 410/6105[21]

The 410/6105 drum is a vertical cylindrical tank with a convex bottom and roof, approximately three (3) meters high, two (2) meters in diameter and twenty-one (21) millimeters thick, fixed to a skirt approximately three and a half (3.5) meters long, designed to receive BOG propane from the 405/6107 heat exchanger. The tank is made of ASME SA 516 grade 60 carbon steel.

Table.III.3 - Technical characteristics of the 410/6105 storage tank

Parameter	value	Unit
Pressure		
Service	0.7	MPaG
Design	1.47	MPaG
Temperature		
Service	- 24	°C
Design	- 29 / 38	°C
Dimension		
Height	2.8	m
Diameter	2	m
Thickness	21	mm
Corrosion allowance	1.6	mm
Volume	10.9	m3
Weight		
Vacuum	7000	Kg
In use	15000	Kg
Full of water	23000	Kg

III.1.1 Suction tank 410/6103[22]

The 410/6103 suction balloon is a vertical cylindrical tank with a convex bottom and roof, approximately two meters and six hundred millimeters (2.6) high, with a capacity of two liters. (2) meters in diameter and seventeen (17) millimeters thick, and is attached to a skirt measuring approximately one meter and two hundred millimeters (1.2). The balloon is made of ASME SA 516 grade 60 carbon steel.

Table.III.4 - Technical characteristics of the 410/6103 storagetank

Parameter	value	Unit
Pressure		
Service	0.08	MPaG
Design	1.15	MPaG
Temperature		
Service	- 25.7	°C
Design	- 29 / 38	°C
Dimension		
Height	2.6	m
Diameter	2.2	m
Thickness	17	mm
Corrosion allowance	1.6	mm
Volume	12.7	m3
Weight		
Vacuum	7000	Kg
In use	13000	Kg
Full of water	22000	Kg

III.1.2 Schiller 410/6107 (heat exchanger)[23]

The Schiller 405/6107 is a heat exchanger made up of two essential elements, the shell side through which the refrigerant propane flows and the bundle side through which the BOG propane passes. In this heat exchanger, heat is transferred between the two products, where the BOG propane transfers some of its enthalpy to the refrigerant propane, thus cooling the BOG propane, while some of the refrigerant propane evaporates and is then sent to the 410/6103 tank to be drawn off by the HOWDEN compressors.

III.1.2.1 Beam side:

The bundle side comprises 394 holes, i.e. 197 smooth U-shaped tubes, with an external diameter of 19 millimeters and a distance of 25.4 millimeters between two-hole centers (the pitch), a length of 6 meters, and weighing approximately 4853 kilograms, manufactured from ASTM A 334 Gr6 carbon steel, intended for the manufacture of tubes used in low-temperature applications, with the following chemical composition:

Table.III.5 - Chemical composition of carbon steel ASTM A334 Gr6

C	If	Mn	Pb	S
0.30 %	≤ 0.10%	0.29 - 1.06 %	0.025 %	0.025 %

The tubes are designed for a design pressure of 29.6 bar and a design temperature of between -46 and 55 °C and are mounted on a 0.9-meter diameter tube plate made of ASTM A 350 LF2 steel with the following chemical composition:

Table.III.6 - Chemical composition of ASTM A 350 LF2 steel

C	Mn	If	Pb	S	Cr	Ni	Mo
0.30 %	0.6 - 1.35 %	0.15 - 0.3 %	0.035 %	0.040%	0.3 %	0.4 %	0.12 %

The tubes are machined in a U shape, given the significant difference between the temperature of the BOG propane, which is around 60°C at the Schiller inlet, and the temperature of the refrigerant propane, which is around -27.3°C.

The calender is the metal envelope that surrounds the bundles. It has a specific shape designed in carbon steel ASTM A516 Gr 60, and is 7.94 meters long. Depending on its shape, the calender side has two different diameters, one side with a diameter of 1.6 meters and the other with a diameter of 0.9 meters. The covers are made from ASTM A 515 Gr carbon steel.
60. The steels used have the following composition:

Table.III.7 - Chemical composition of ASTM A515 and 516 GR60 steels

ASTM	C	Mn	If	Pb	S
A 515 Gr 60	0.27 %	0.90 %	0.15 - 0.40 %	0.035 %	0.035 %
A 516 Gr 60	0.23 %	0.85 - 1.20 %	0.15 - 0.40 %	0.35	0.35

III.1.3.1 Compressors COOPER 430/6101 D/E[24]

These are multi-stage centrifugal compressors driven by an electric motor. These compressors will compress the propane vapors from the 420/6104 storage tank and the 410/6106 propane expansion tank.
The motor compressor unit consists of:

III.1.3.2 Three-stage centrifugal compressor

Cooper is a centrifugal compressor with a horizontal axis rotating at high speed. It consistsofa1^{er} and 2ème stage rotor, a 3ème stage rotor, an impeller, a radial diffuser, a volute, radial and axial clockwise and counter-clockwise bearings, suction and discharge piping.... The technical characteristics of Cooper compressors are:

Table.III.8 - Technical characteristics of Cooper compressors

ITEM	UNITS	Value
Service		NORMAL
Gas		propane
Suction pressure	kg/cm^2	0.400
Suction temperature: ✓ 1er floor ✓ 2ème floor ✓ 3ème floor	 °C °C °C	 -44.5 9.70 38.50
Suction flow	kg/h	15
Discharge pressure	kg/cm^2	07
Discharge temperature	°C	60
Discharge flow	kg/h	15

Sealing at each stage of the compressors is ensured by tandem dry face seals (primary and secondary seals), whereby a process gas circuit is connected to the primary seal, and another nitrogen circuit to the secondary seal. The compressors are also equipped with an oil seal system at the gearbox of each stage, from which a small quantity of instrument air is sent to each oils e a l.

This is designed to prevent atmospheric air from entering the gearbox through the oil seal as a result of the vacuum system.

III.1.4.1 Electric drive motor

It is a horizontal shaft motor with ATEX type EEx protection IIB T4 IP55. The motor has the following characteristics:

Table.III.9 - ABB motor technical data

RATED POWER	1050 KW
VOLTAGE	5500 V +/- 10%
EMPTY CURRENT	22 A
RATED CURRENT	126 A
CRITICAL SPEED	2200 rpm
TOTAL WEIGHT	5715 Kg

The main engine components are:

- Stator block
- Rotor block
- Support aprons
- Fan and fan cover
- Roller bearings
- Carcass

The motor is fitted with a cooling system activated by a fan installed on the end of the shaft, onthe opposite side to the coupling.

III.1.4.2 Oil pumps

The system is equipped with two oil pumps, one electric for starting and stopping the compressor and the other driven during normal operation. These pumps provide the pressure needed to lubricate the various compressor bearings and drive units.

a. **The oil cooler**
b. **The nitrogen generator**
c. **Control panel**
d. **Air cooler (attached to the compressor)**

III.1.4.3 HOWDEN 430/6102 C/D compressor[25]

The HOWDEN compressor package is used to compress the refrigerant propane vapors drawn from the 410/6103 storage tank. The package consists of the following elements

- The main drive motors
- The gearbox
- Compressor
- Filter
- Primary separator and oil tank
- Secondary separator
- Oil filter
- Oil and gas air coolers
- Oil pumps
- Gearbox lubrication system
- Control panel

III.1.4.3 HOWDEN WRViTS 510 compressor

The HOWDEN screw compressor is a controlled volumetric capacity, where the oil floods the machine's rotating elements.

Compression is ensured by the meshing of two rotors (screws) with an asymmetrical profile on two shafts housed in an appropriate casing (the housing). The action of the rotors is entirely rotary and there are no valves or other equivalent parts.

Precision-machined rotors are called male and female. The male (drive) rotor has four lobes, which mesh with six splines in the female (driven) rotor, having the same external diameter.

Compressor lubricating oil is injected into the rotor and inlet bearing spaces / output at gas discharge pressure, over 3.1 bar.The

various components of the compressor are:

- The housing
- The inlet end cover (suction)
- The outlet end cover (discharge)

- Spool valve
- Bearings
- Male and female rotors
- Gasket

Compression takes place in three phases: suction, compression and delivery.

Initially, the refrigerant gas is drawn into the compressor through a filter mounted on the suction line and a non-return valve, from where it reaches the screw thread of the open rotors on the suction side. The progressive rotation of the rotors locks the gas intake port. Continued progressive rotation will reduce the space occupied by the gas causing its compression. As the rotation progresses, oil is injected to lubricate the rotors.

bearings, sealing and heat removal from the compression. When the space between the rotors is exposed to the outlet port, the gas is evacuated.

At the outlet, the compressed gas, mixed with the lubricating oil, passes through the primary separator, where most of the oil separates from the gas stream due to the reduction in velocity. The gas and entrained oil droplets then pass through a stainless-steel wire mesh separator element mounted in the upper part of the drum, where oil separation takes place. The separated oil falls by gravity into the base of the drum.

The gas leaving the primary separator contains approximately 35 to 50 ppm oil by weight. The gas then passes through the high-efficiency secondary separator, incorporating replaceable coalescing elements that are effective in removing liquid oil.

III.1.4.4 The strainer:

The suction strainer is fitted with 60 removable elements (250 microns) which must be checked and cleaned if necessary during the annual shutdown periods.

III.1.4.5 The primary separator

The primary separator is designed for initial separation of the oil mixed with the gas during compression and is also used as an oil reservoir for the lubrication system. Separation is achieved by directing the discharge gas first through a diffuser and then through an anti-fog element mounted on a plate near the top of the vessel.

III.1.4.6 Secondary separator

The secondary separator is fitted in the discharge line downstream of the primary separator. This is fitted with coalescing elements to reduce the oil to 5 ppm by weight.

The liquid coalesced in bulk from the filter elements is returned to the compressor intake.

III.1.4.7 The gas air cooler

The gas air cooler is part of the package, and is designed to cool the gas coming from the compressor from 69.2°C to 60°C. The air cooler consists of a casing beneath which a motor and fan are mounted, providing an air flow to the bundle section passing through the top of the casing.

III.1.4.8 The gearbox

This is a single-stage speed-increasing unit with input and output shaft axes on the same horizontal plane. The electric motor drives the input impeller shaft, and the compressor is driven by the input pinion shaft, via flexible couplings.

III.1.5.1 Air cooler 405/6104

The air/gas heat exchanger consists of an electric motor rotating at 1,500 rpm, which drives a six-bladed aluminum fan via a belt. These elements supply air to the upper part of the air cooler,

which is made up of bundles 12.5 meters long and 3.59 meters wide, housing 224 ASTM A214steel tubes with a diameter of 25.4 millimeters and a thickness of 2.108 millimeters. The whole structure is fixed to a metal framework. The steel used to make the tubes has the following chemical composition:

Table.III.10 - Chemical composition of ASTM A214 steel

C	Mn	Pb	S
0.18 %	0.27 - 0.63 %	0.035 %	0.035 %

The components of the air cooler are:

- **Fan:** consists of the following components:
  - **Hub:** made up of two parts, the first of which attaches directly to the shaft and the second to the blades.
  - **The blades:** these are made of an aerodynamic aluminum alloy profile attached to the hub.
- **The shaft:** ensures rotation
- **Bearings:** two bearings are arranged to support the axial and radial forces.
  - **Upper bearing (**ball bearing)**:** this type of bearing supports relatively high radial and axial loads.
  - **Lower bearing** (roller bearing).
- **Pulleys (toothed wheels):** two standard toothed pulleys are installed and connected by a flat toothed belt.
  - **Drive pulley:** attached to the end of the motor to transmit the rotational movement to the driven pulley.
  - **Take-up pulley:** located on the lower part of the transmission shaft.
- **Drive belt:** this is a flat, notched part made of rubber, grooved width ways by teeth. It acts as a link between the driving and driven pulleys, to ensure the transmission of rotational movement.

III.1.5.2 425/6101 D/E pumps[26]

These are two-stage vertical centrifugal pumps that pump commercial propane from the 410/6106 storage tank to the 420/6104 tank.

Table.III.11- Pump technical specifications

Parameter	Value
Capacity	190 m /h^3
Height	65 m
Speed	1485 rpm
Design pressure	0.8 - 4.1 MPaG
Temperature	-45,5°C

Each pump consists of the following components:

- **Electric drive motor**
- **Pump body:** Supports the drive system (motor) and the tank.
- **Drive shaft:** this is the rotating element that drives the hydraulic shaft (of the pump) by means of a coupling.
- **Tank (2 Impellers, 2 Diffusers)** The tank assembly comprises two impellers rigidly mounted on the hydraulic shaft, which rotates, transmitting energy to the liquid. The diffuser contains pressurized liquid, enabling it to be conveyed vertically to the next stage, up to the discharge.
- **Degassing tube:** To evacuate the part of the gas that has evaporated as a result of bubbling.
- **Bearings**
- **Gasket:** Provides a seal to prevent gas leaks.
- **Methanol pot:** contains methanol used for lubrication and cooling
- **Coupling:** this couples the two shafts to transmit mechanical power from the motor to the pump.

III.2.1 Description of the BOG Propane section process[27]

III.2.1.1 Commercial propane circuit

Commercial propane is sent from the refrigeration section, via line 6″D3W9186 PX C70, through the PV6184 valve controlled by the PIC 6184, to the Flash 410/6106 storage tank at a pressure of approximately 0.4 bar. The expansion of the propane allows it to cool to a temperature of -45°C. In this drum the liquid product is drawn off by pumps 425/6101 D/E and sent to storage tank 420/6104, and the vapor phase is combined with vapors from the BAC via line 14″D1W 9326 PX C75. These vapors will be drawn in by COOPER 430/6101 D/E compressors at a pressure of 0.4 bar and a temperature of -44.7°C and a flow rate of 15 Kg/h. These vapors will be compressed in the two compressors and discharged to the heat exchanger (Schiller) 405/6107 at a pressure of 7 bars and a temperature of 60°C via the air condensers 405/6101 D/E, knowing that 5.18 Kg/h are returned to the storage tank 410/6106 as recycling.

At the 405/6107 exchanger, heat transfer takes place between the refrigerant propane coming from the 410/6104 storage tank, which passes through the shell side at a temperature of -27.3°C, and the commercial propane which passes through the bundle side (tube). The commercial propane, cooled to -24°C, is sent to the BOG 410/6105 propane buffer tank.

By design, the liquid BOG propane must pass through the de-ethanisation column, but this is stopped, so the liquid BOG propane products go directly to the 410/6106 flash drum and are then sent to the storage tank the Figure.II.5 bellow illustrate the process.

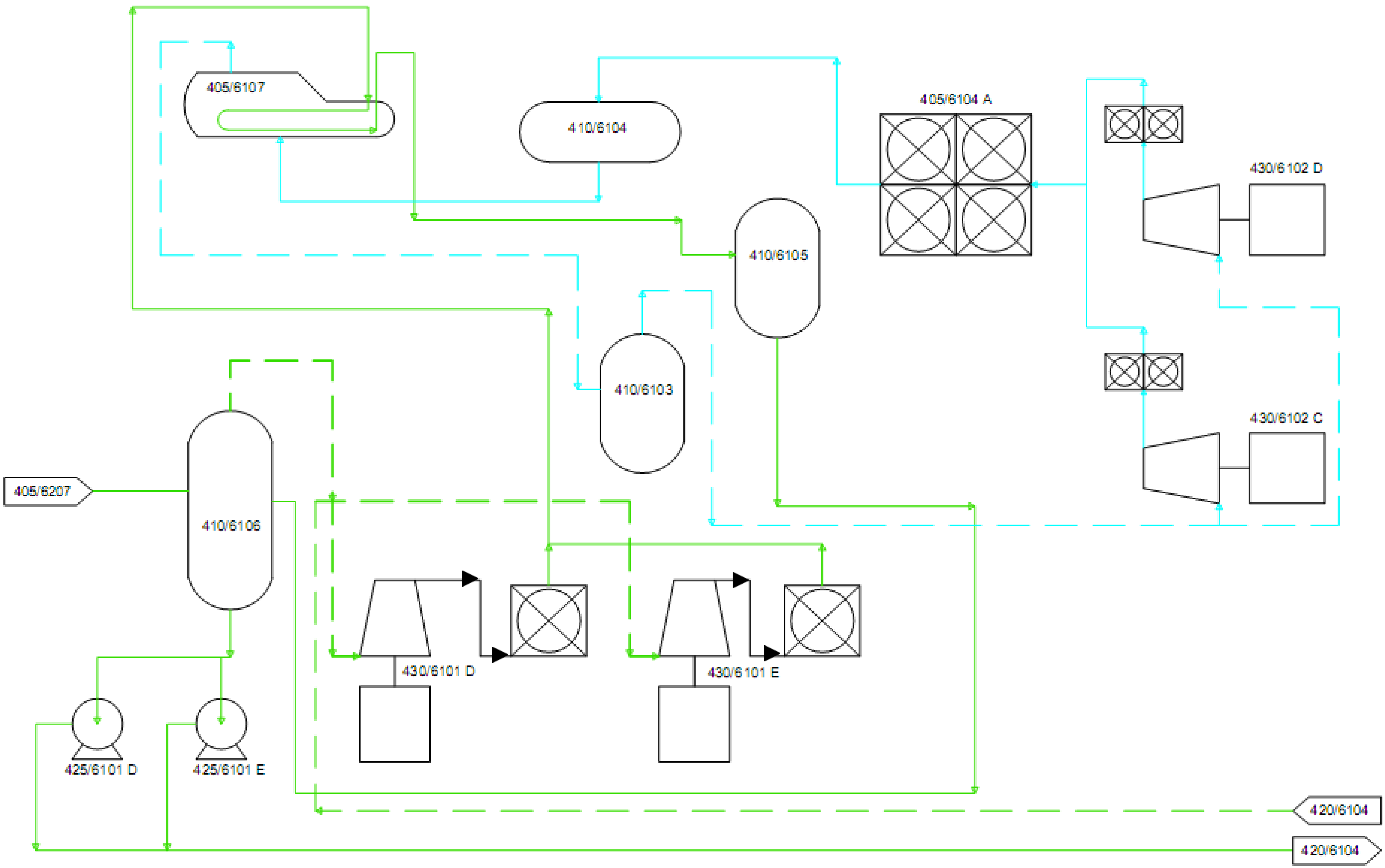


Figure.III.1 - Block diagram of the BOG section process

III.2.1.2 Propane refrigerant circuit

The refrigerant propane stored in the tank 410/6104 is sent to the shell side of the exchanger 405/6107 where its pressure is 0.9 bar and its temperature is -27.3°C. The vapors generated by the heat transfer phenomenon at the exchanger are directed to the suction tank 410/6103 at a pressure of 0.9 bar and a temperature of -26.9°C. From this tank (410/6103) the vapors are drawn off by the HOWDEN 430/6102 C/D compressors, where they are compressed and discharged at a pressure of 16 bar and a temperature of 65°C. They are then liquefied in the 405/6104 An air condenser and recovered in the 410/6104 tank at a pressure of 16 bar and a temperature of 42°C.

III.3.1 Risk analysis

There are several risk analysis methods and techniques that organizations use to assess and manage risks effectively. Here are some commonly used ones:

Qualitative Risk Analysis[28]: This method involves assessing risks based on subjective judgment rather than numerical data. Risks are typically evaluated on qualitative scales suchas low, medium, or high, or using descriptive terms like negligible, moderate, or severe. Techniques such as risk matrices, risk registers, and expert judgment are often employed in qualitative risk analysis.

Scenario Analysis[29]: Scenario analysis involves exploring various hypothetical scenarios and assessing their potential impact on the organization. This method helps identify vulnerabilities and opportunities by considering different combinations of risk factors and events. Scenario planning and “what-if” analysis are common techniques used in scenario analysis.

The Hazard and Operability (HAZOP)[30]**:** analysis is a systematic method used to identify and assess potential hazards and operability issues in process systems. It involves a multidisciplinary team systematically examining process parameters to identify deviations from design intent that could lead to hazardous situations. By analyzing process nodes and deviations, HAZOP helps pinpoint potential causes of accidents and enables the implementation of preventive measures to enhance safety and operational efficiency. This technique is widely used in industries such as chemical, petrochemical, and pharmaceutical manufacturing to mitigate risks and process safety.

III.3.2 Risk analysis using the FMEAC method

To carry out the FMECA analysis, we first collected information on the systems under study, namely:

1. Cooper 430/6101 D/E compressors
2. HOWDEN 430/6102 C/D compressors
3. EBARA 425/6101 D/E pumps
4. Air cooler 405/6104A

The information comes from manuals and technical documents relating to each system, as wellas feedback and records relating to equipment failures.

The second step was to decompose the systems into sub-systems and elements:

- Cooper 430/6101 D/E Motor Compressors:
  1. Electric drive motor (ABB)
  1. Cooper centrifugal compressor
  2. Lubrication system
  3. Air cooler
- HOWDEN 430/6102 C/D Motor Compressors
  1. SIEMENS electric motor
  2. HOWDEN screw compressor
  3. Gearbox
  4. Auxiliaries
- EBARA 425/6101 D/E electric pumps
  1. Electric motor
  2. Vertical centrifugal pump

Each sub-system was then broken down into components and each component was analyzedusing the FMECA method, identifying its failure modes, causes and consequences as follows:

Table.III.12 - Breakdown of the 430/6101 compressor into sub-systems

Cooper 430/6101 motor compressor			
ABB electric motor	**Centrifugal compressor**	**Lubrication system**	**Air cooler**
Stator block Rotor block Motor body Bearings Ventilation flanges	Gearbox Shaft Impeller Radial diffuser Seal Radial bearing Thrust bearings Gearbox shaft Toothed wheels (gear) Volute	Oil tank Trailer oil pump Auxiliary oil pump Piping Filter	Electric motor Belts Bearings Toothed wheels Fan blades Harnesses

Section	**BOG Propane**		**System**	**Cooper motorbike compressor**						
Circuit	**Commercial propane**		**Subsystem**	**ABB electric motor**		**Tag Number**				**430/6101 D/E**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk** F	G	D	C	**Comments**
Stator block	Chalk the rotating field	- Degradation of winding insulation	- Voltage variation - Mechanical vibration - Premature ageing - Overheating	- Short circuit - Engine stops - Compressor stop	SEPAM PT100 relay	1	3	1	3	Check and control connections. Monitoring operating parameters
		Short circuit	- Overheating (overload) - Bare conductor - Insulation fault between coils	- Engine stops - Compressor stop	SEPAM PT100 relay	1	3	1	3	
Rotor block	Ensures the rotation movement	Rotor-stator friction	- Bearing wear - Shaft misalignment - High levels of vibration	- Overheating - Insulation wear - Engine stop	SEPAM relay	1	3	1	3	Check the condition of the bearings, and monitor the intensity of the vibrations.
		Shaft twisting	- Blocking - Warm-up - Vibrations	- Vibration - Shear	Noise	1	3	3	9	Given the cross-section of the tree, the probability of these failure modes occurring remains very high. low.
		Shaft bending	- Clumsy	- Vibration - Overheating	Noise	1	3	3	9	
Motor body	Contain and protect the elements	- Cracking or breaking	- Corrosion - External shock	- Risk of water ingress - Risk of accidents for staff - Degradation of isolations in windings	Visual inspection	1	5	3	15	The environment is corrosive (close to the sea). Inspection remains essential, even if the probability of failure is low.
Terminal box	Connection point	Overheating of terminals (calcination) Loss of seal	- Loose connections - Loose lid	- Loss of ATEX protection - Water seepage	/	1	3	4	12	If possible, provide a means of detection.
Bearings	Supporting and guiding the tree	- Wear and tear	- Ageing - Lubrication fault - Overload	- Warm-up - Vibration - Engine lock	Probes connected to the PC	2	2	3	12	Monitor the condition of bearings and keep them well lubricated

Flanges	Bearing housing	- Torn metal at the lodge - Cracking	- Lubrication fault - Overheating - Vibration	- Rotor lock - Rotor misalignment	/	1	2	3	6	Monitor the intensity of vibrations and lubrication conditions
Ventilation	Cooling	- Imbalance	- Bearing wear	- Bad	SEPAM relay	1	2	1	2	Check the condition of the bearings
		- Plugging of cooling	- Deposition of impurities	cooling - Overheating	PT 100	2	2	1	4	Clean the cooling

Section	BOG Propane		System	Cooper motorbike compressor						
Circuit	**Commercial propane**		**Subsystem**	**Cooper centrifugal compressor**		**Tag Number**				**430/6101 D/E**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk**				**Comments**
						F	G	D	C	
Gearbox housing	To house and protect the sprockets and contain the lubricating oil	- Crack - Break	- Vibration - Corrosion - External mechanical shock	- Lubricating oil leak - Risk of water ingress - Compressor stop	- Visual	1	3	3	9	Carry out regular checks to identify any corrosion and take action as soon as possible.
Tree	Ensures rotation and supports the impellers	Twist	- Blocking - Warm-up	- Vibration - Shear	- Sensor vibration	1	3	4	12	The vibration sensor detects the effects, not the causes or the mode of vibration. of failure
		Flexion	- Clumsy	- Vibration	- Vibration sensor	1	3	4	12	
		Damage	- High levels of vibration - Pumping phenomenon - Heavy wear on bearings	- Compressor damage and shutdown	- Vibration sensor	1	3	1	3	Monitor the condition of the bearings, as well as the operating compressor operation
Impeller	Transfer of kinetic energy (rotation) to increase gas velocity	Damage to the impeller	- Entrainment of gas in the liquid phase. - High gas flow - Pumping phenomenon	- Compressor damage and shutdown	- vibration sensor - LSHH and LAHH balloon 410/6106	2	3	1	6	Maintaining instruments (LSHH and LAHH). Monitor operating conditions. Inspections of internal compressor components.
		Damage to blades (change in angle ofrepose)	- Entrainment of gas in the liquid phase. - High gas flow - Pumping phenomenon	- Damage to a stage and compressor shutdown	- vibration sensor - LSHH and LAHH balloon 410/6106	1	3	1	3	
Radial diffuser	Transforms kinetic energy into pressure	Cracking and tearing of metal	- Entrainment of gas in the liquid phase. - Material defect - Corrosion	- Damage to a floor - Compressor damage and shutdown	- Inspection of internal components - LSHH and LAHH balloon 410/6106	1	3	3	9	Monitor operating conditions. Inspection of compressor internals
Gasket	Ensures compressor seal (prevents gas exhaust	- Leakage	- Process gas supply fault - Nitrogen supply fault	- Propane leak - Formation of ATEX atmosphere with risk of explosion	- Visual - Noise - Olfactory - Gas detectors	1	4	1	4	The trim is of the Tandem type.

	to the atmosphere)		- Mechanical wear of the trim	or fire						
Radial bearing	Supporting and guiding the rotor (supporting radial loads)	- Wear and tear	- Lubrication fault - Ageing - Pumping - Clumsy - Misalignment	- Blocking and incorrect rotation - Vibration - Stopping the machine	- Vibration sensor - Thermocouple	2	2	4	16	Sensors detect effects, not causes or failure modes. Monitor the condition of the bearings and keep them well lubricated.
Thrust bearings	Limiting axial movement	- Wear and tear	- Lubrication fault - Overload - Incorrect alignment	- excessive gambling - Vibration - Rotor displacement	- Vibration sensor - Thermocouple	2	2	4	16	
Speed multiplier shaft	Transmitting motion and increasing rotation speed	Twist	- Blocking	- Shear - Vibration - Compressor stop	- Vibration sensor	1	3	3	9	Given the cross-section of the shaft, the probability of torsion and bending is very low, but it is still important to monitor the condition of the shaft.
		Flexion	- Clumsy - Misalignment	- Vibration - Gear heating - Compressor stop	- Vibration sensor - Thermocouple	1	3	3	9	
		Damage	- High levels of vibration - Heavy wear on bearings	- Compressor stop	- Vibration sensor	1	3	1	3	Maintain the levels periodically and rigorously.
Toothed wheels	Ensure the gearing and transmission of movement	Wear or breakage of one or more teeth	- Lubrication fault - Ageing - Incorrect adjustment of inter-teeth clearance and run-out clearance - Misalignment	- Vibration - Warm-up - Blocking - Compressor stop	- Vibration detector - Thermocouple	1	3	3	9	Inspect the condition of the wheels and keep them well lubricated. The detectors detect the effect and not the causes or failure.
Volute	Gas routing	- Wear and tear - Cracks - Leakage	- Erosion - External mechanical shock - Corrosion - Damage to seals	- Pressurized gas leak. - Formation of an ATEX atmosphere with risk of explosion and fire	- Visual - Olfactory - Gas detectors	1	4	4	16	Detection modes act late, so a means of detection or warning must be provided. monitoring the condition of the volute.

Section	BOG Propane		System	Cooper motorbike compressor						
Circuit	Commercial propane		Subsystem	Lubrication system		Tag Number				430/6101 D/E
Element	Function	Failure mode	Cause	Effect	Detection	Risk F	Risk G	Risk D	Risk C	Comments
Oil tank	Containing the oil	Loss of containment (cracks, holes)	- Corrosion - External mechanical shock	- Oil leak - Pollution - Risk of poor lubrication due to lack of oil	- Level check (LG) - Visual	1	2	3	6	NDT (thickness measurement) Wall maintenance.
Auxiliary oil pump	- Supplies lubricant before start-up and during shutdown. - Ensures that pressure is maintained at a normal level in the event of a problem with the attached pump	Stopping the electric motor driving the pump	- Power supply fault - Short circuit - Failure of one or more engine components - Overheating	- Stopping the pump - Poor lubrication, with the risk of overheating bearings and gears - Risk of engine stoppage and compressor	/	1	3	4	12	Perform frequent start-up tests. Check connections.
		Shaft imbalance	- Clumsy - radial clearance	- Misalignment - Vibration - Warm-up	Visual Inspection	1	2	3	6	
		Leakage	- Trim wear and ageing - Seal wear	- Oil leak	Pressure Gauge Visual	2	2	3	12	Change the seals according to their useful life and check the condition of the lining
Attached oilpump	- Ensures system lubrication during normal operation	Uncoupling	- Coupling wear - Loose coupling - High levels of vibration	- Stopping the pump - Starting the auxiliary pump	Pressure Gauge Inspection	2	2	3	12	Monitor the intensity of vibrations, tightness and condition of couplings
		Leakage	- Trim wear and ageing - Seal wear	- Oil leak	Pressure gauge Visual	1	2	3	6	Change the seals according to their useful life and check the condition of the trim
Piping	Ensures lubricant flow	Leaks	- Corrosion - Shock - Connection fault	- Pressure drops - Poor lubrication - Risk of ignition on contact with a hot point	Pressure gauge Visual	2	2	2	8	CND Visual inspection of connections (flanges)

Filters	Filter the oil	Filter clogging	- Presence of solid particles in the oil - Filter saturation	Increase in the pressure difference between upstream and downstream of the filter	Pressure gauges	3	2	1	6	Changing filters

Section	**BOG Propane**		**System**	**Cooper motorbike compressor**						
Circuit	**Commercial propane**		**Subsystem**	**Air coolers**		**Tag Number**				**430/6101 D/E**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk** F	G	D	C	**Comments**
Electric motor	Fan drive	Damage to the engine	- Overload - Surge voltage - Cooling fault	- Stopping the aero plane	SEPAM PT100 relay	2	3	1	6	Check and control connections. Monitoring operating parameters
		Short circuit	- Overheating (overload) - Bare conductor - Insulation fault between coils	- Engine stop	SEPAM PT100 relay	1	3	1	3	
		Rotor-stator friction	- Bearing wear - Shaft misalignment - High levels of vibration	- Overheating - Insulation wear - Engine stop	SEPAM relay	1	3	1	3	Check the condition of the bearings, and monitor the intensity of vibrations.
		- Cooling system shutdown	- Bearing wear - Uncoupling - Damage to the blades	- Overheating - Damage to the engine	SEPAM PT100 relay	1	2	1	2	Check bearings and couplings. Check the condition of the blades
Belts	Provides the link between the gears	- Worn belt - Tensioned belt - Torn belt	- Ageing - Cutting wheel teeth - Incorrect belt tension - Misalignment	- Engine idling - Non-driven fan - Uncooled gas/oil	- Motor amperage - Bundle outlet gas temperature	3	2	3	18	Check the condition of the belts and their tension. Check the sprockets Use belts of the correct good quality
Bearings	Supporting and guiding the tree	- Wear and tear	- Ageing - Lubrication fault - Overload	- Vibration - Imbalance	- Noise - Vibration sensor	2	2	4	16	Monitor and maintain the condition of bearings well lubricated
Fan blades	Moving air	- Damage	- Vibration - External mechanical shock	- Clumsy - Cooling fault	Noise Inspection Vibration sensor	2	3	1	6	Carry out regular visual checks Maintaining the vibration sensor
Bundles	Carrying the fluid	- Crack - Plugging (oil bundles)	- Pressure relief - Corrosion - External mechanical shock - Erosion	- Gas leak and formation of an atmosphere (ATEX) - Oil leak	Gas detector inspection	1	4	3	12	Monitor operating parameters.

		Wear/fouling vanes	- External mechanical shock	- Yield reductionof the air cooler	-Visual	2	2	3	12	Cleaning the fins

Table.III.13 - Breakdown of the 430/6102 compressor into sub-systems

Howden 430/6102 Motor Compressor			
Electric motor SIELENS	**Screw compressor**	**Gearbox**	**Auxiliaries**
Stator block Rotor block Motor body Bearings Ventilation flanges	Carter Male and female screws Bearings Gasket Filter Power drawer	Input shaft Output shaft Flexible coupling Bearings Bearing seals Housing	Primary separator Secondary separator Oil pump Oil filter Oil drain pot Gas cooler Oil cooler

Table.III.14 - Breakdown of the EBARA 425/6101 electric pump into sub-systems

Electropump EBARA 425/6101	
Electric motor	**Vertical centrifugal pump**
Stator block	Pump body
Rotor block	Hydraulic shaft
Terminal box	Tank
Motor body	Impellers
Bearings	Diffusers
Ventilation	Gasket
	Rolling Bearings
	Methanol pot
	Coupling

Table.III.15 - Breakdown of 430/6101 air cooler into sub-systems

Air cooler 405/6104 A
Electric motor
Belts
Bearings
Toothed wheels
Fan blades
Harnesses

Section	**BOG Propane**		**System**	**HOWDEN motor compressor**						
Circuit	**Propane refrigerant**		**Subsystem**	**SIEMENS electric motor**		**Tag Number**				**430/6102 C/D**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk** F	G	D	C	**Comments**
Stator block	Chalk the rotating field	- Degradation of winding insulation	- Voltage variation - Mechanical vibration - Premature ageing - Overheating	- Short circuit - Engine stops - Compressor stop	SEPAM PT100 relay	1	3	1	3	Check and control connections. Monitoring operating parameters
		Short circuit	- Overheating (overload) - Bare conductor - Insulation fault between coils	- Engine stops - Compressor stop	SEPAM PT100 relay	1	3	1	3	
Rotor block	Ensures the rotation movement	Rotor-stator friction	- Bearing wear - Shaft misalignment - High levels of vibration	- Overheating - Insulation wear - Engine stop	SEPAM relay	1	3	1	3	Check the condition of the bearings, and monitor the intensity of the vibrations.
		Shaft twisting	- Blocking - Warm-up - Vibrations	- Vibration - Shear	/	1	3	3	9	Given the cross-section of the tree, the probability of these failure modes occurring remains very high. low.
		Shaft bending	- Clumsy	- Vibration - Overheating	/	1	3	3	9	
Terminal box	Connection point	Overheating of terminals (calcination) Loss of seal	- Loose connections - Loose lid	- Loss of ATEX protection - Water seepage	/	1	3	4	12	If possible, provide a means of detection.
Motor body	Contain and protect the elements	- Cracking or breaking	- Corrosion - External shock	- Risk of water ingress - Risk of accidents for staff - Degradation of winding insulation	Visual inspection	1	5	3	15	The environment is corrosive (close to the sea). Inspection remains essential, even if the probability of failure is low.
Bearings	Supporting and guiding the tree	- Wear and tear	- Ageing - Lubrication fault - Overload	- Warm-up - Vibration - Engine lock	Probes connected to the PC	2	2	4	16	Monitor the condition of bearings and keep them well lubricated

Flanges	Bearing housing	- Torn metal at the lodge - Cracking	- Lubrication fault - Overheating - Vibration	- Rotor lock - Rotor misalignment	Noise	1	2	3	6	Monitor the intensity of vibrations and lubrication conditions
Ventilation	Cooling	- Imbalance	- Bearing wear	- Bad	SEPAM relay	1	2	1	2	Check the condition of the bearings
		- Plugging of cooling	- Deposition of impurities	-cooling overheating	PT 100	2	2	1	4	-Clean the cooling

Section	**BOG Propane**		**System**	**HOWDEN motor compressor**						
Circuit	**Propane refrigerant**		**Subsystem**	**HOWDEN screw compressor**		**Tag Number**				**430/6102 C/D**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk**				**Comments**
						F	G	D	C	
Carter	Housing and protecting the various compressor components	- Crack - Breaks	- Corrosion - External mechanical shock	- Gas leak - Formation of an ATEX atmosphere with risk of fire or explosion - Oil leak	Visual	1	3	3	9	Carry out regular checks to identify any corrosion and act as soon as possible.
Male and female screws	Compression of gas through rotation	- Wear and tear	- Friction - Lubrication fault - Ageing - Incorrect adjustment of screw clearances	- Warm-up - Spacing between lobes and screw splines - Vibration - Incorrect gas compression	- Vibration sensor - Thermocouple	1	4	4	12	Vibrations are the effect of the failure, so detection is a little late. On the other hand, monitoring operating parameters and inspecting components can ensure that the machine is in good working order. prevention of these defects
		- Imbalance	- Clumsy - Shaft misalignment - Poor shaft coupling	- Vibration - Compressor lockout - Compressor stop	- Vibration sensor	1	4	4	12	
Bearings	Support and guide the two screws	- Wear and tear	- Ageing - Lubrication fault - Warm-up	- Vibration - Compressor lock	- Vibration sensor - Thermocouple	2	2	3	12	Monitor and maintain the condition of bearings well lubricated
Gasket	Seals the compressor	- Leakage	- Wear and tear - large axial displacement - Poor lubrication	- Gas leak and formation of ATEX with risk of fire or explosion. - oil leak	- Pressure transmitter	2	3	1	6	Check the condition of the seal periodically and ensure it is well lubricated.
Filter	Filtering the gas	- Poor filtration	Fouling	- Increase in upstream pressure - Reduced suction flow	- Pressure Indicator Device (PDI)	1	1	4	4	Maintain the pressure gauge to avoid false readings
Drawer power	Flow rate adjustment gas on start-up	- Drawer lock power	- Solenoid valves faulty	- The electric motor does not does not start.	- Limit switch	2	3	3	18	Ensure the maintenance of the solenoid valve and

	for the protection of electric motor		- Piston seal damaged - oil leak							drawer components.

Section	BOG Propane		System	HOWDEN motor compressor						
Circuit	**Propane refrigerant**		**Subsystem**	**Gearbox**		**Tag Number**				**430/6102 C/D**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk** F	G	D	C	**Comments**
Input shaft	Gearbox drive	Twist	- Blocking	- Vibration - Compressor stop	Sensor vibration	1	3	4	12	The vibration sensor detects the effects, not the causes or mode of failure
		Flexion	- Clumsy	- Vibration - Gear heating - Compressor stop	- Vibration sensor - Thermocouple	1	3	4	12	
		Damage	- High levels of vibration - Heavy wear on bearings	- Compressor stop	- Vibration sensor	1	3	1	3	Monitor the condition of the bearings and the operating conditions of the compressor
Output shaft	Compressor drive	Twist	- Blocking	- Shear - Compressor stop	- Sensor vibration	1	3	4	12	The vibration sensor detects the effects, not the causes or mode of failure
		Flexion	- Clumsy - Misalignment	- Vibration - Gear heating - Compressor stop	- Vibration sensor - Thermocouple	1	3	4	12	
		Damage	- High levels of vibration - Heavy wear on bearings	- Compressor stop	- Vibration sensor	1	3	1	3	Monitor the condition of the bearings, as well as the operating compressor operation
Flexible couplings	Connecting two shafts	Uncoupling	- Loose coupling - Intense vibrations	- Compressor stop	- Vibration sensor	1	2	4	8	rapid intervention as soon as the intensity of the vibrations change will avoid the effects

Bearings	Supporting and guiding the tree	Wear and tear	- Ageing - Heavy load - Assembly fault	- Imbalance - Eccentricity - Vibration - Overheating	- Vibration sensor - Thermocouple	1	2	4	8	Sensors detect effects, not causes or faults. Monitor the condition of the bearings and keep them well lubricated.
Gasket bearings	Waterproofing	Wear and tear	- Ageing	- Oil leak - Warming up the bearing	- Visual	1	2	4	8	Change the seal according to their prescribed duration of use
Box	Protecting internal components	Cracks, breaks	- Corrosion - External mechanical shock	- Oil leak	- Visual	1	3	3	9	Carry out periodic checks to identify any corrosion

Section	BOG Propane		System	HOWDEN motor compressor						
Circuit	Propane refrigerant		Subsystem	Auxiliaries		Tag Number				430/6102 C/D
Element	Function	Failure mode	Cause	Effect	Detection	Risk				Comments
						F	G	D	C	
Primary separator	Separating the oil from the gas Containing the oil	Loss of containment	- Corrosion - Crack - External mechanical shock - Worn seals	- Gas leak - Formation of an atmosphere (ATEX) - Oil leak	LT level transmitter LG ice level	1	3	4	12	Thickness measurement (NDT) Regular replacement of seals.
Secondary separator	Separating the oil from the gas	Loss of containment	- Worn seals - Corrosion - Crack - External mechanical shock	- Oil leak - Gas leak and risk the formation of an atmosphere (ATEX)	PDI 905	2	2	4	16	CND Regular replacement of seals.
Oil pump	Delivering lubricant under pressure	Stopping the electric motor driving the pump	- Power supply fault - Short circuit -Failure of one or more engine components - Overheating	- Lubrication fault - Compressor overheating	/	1	3	4	12	Perform frequent start-up tests. Check connections.
		Shaft unbalance	- Clumsy	- Vibration - Stopping the pump	/	1	3	4	12	Stop and check
		Uncoupling	- Wear on bearings	- Lubrication fault - Compressor overheating	/	1	3	4	12	Check the condition of the bearings. Keep the bearings well lubricated.
		Leakage	- Trim wear and ageing - Seal wear - Vibration	- Oil leak	/	3	2	3	18	Change the seals according to their useful life and check the condition of the trim
		Shaft twisting	-Blocking	- Stopping the pump - Poorly lubricated compressor - Warm-up	/	2	3	4	24	Check the condition of the bearings and the alignment of the shaft. Keep the bearings well lubricated
		Defective bearings	- Overload - Poor lubrication		/	3	2	4	24	

				compressor						
Oil filter	Filter the oil	- Fouling	- Presence of impurities in the oil	- Drop in oil pressure downstream of the filter - Compressor stop	PDI	3	1	1	3	Changing filters
Oil drain pot	Trim oil recovery	- Loss of containment	- Corrosion - Crack - worn seal	- Oil leak	LG Visual	3	1	2	6	Check oil level Inspect condition of walls the tightness and condition of the seals.
Gas air cooler	Cooling the gas	- Triggering on start-up	- Electrical fault - Failure of one or more components of the engine	- Stopping the air cooler - Uncooled gas	/	2	3	4	24	Perform start-up tests frequently. Check the connections.
		- Damage to the blades	- Vibration - External mechanical shock	- Vibration - Clumsy - Cooling fault	VAHH - V1 (vibration detector)	2	3	2	12	Maintain detectors Perform periodic visual checks
		- Worn bearings	- Ageing - Lubrication fault - Heavy load	- Vibration - Blocking - Stopping the aero plane	Noise Visual inspection	2	2	3	12	Monitor and maintain the condition of bearings well lubricated
		- Sheared shaft	- Significant vibration	- Stopping the aero plane	VAHH - V1	2	3	1	6	Maintain detectors Perform visual checks periodically If necessary, dismantle and check
		- Non-driven fan	- Uncoupling	- Stopping the aero plane - Motor turns in a vacuum - Motor overload	Inspection	1	2	3	6	Check that couplings are tight
		- Triggering on start-up	- Electrical fault - Failure of one or several engine components	- Stopping the air cooler - Uncooled gas	/	2	3	4	24	Perform start-up tests frequently. Check the connections.

Oil cooler	Cooling the oil	- Damage to the blades	- Vibration - External mechanical shock	- Vibration - Clumsy - Cooling fault	VAHH-V2 (vibration detector)	2	3	1	6	Maintain detectors Perform periodic visual checks
		- Worn bearings	- Ageing - Lubrication fault	- Vibration - Blocking	Noise Visual inspection	2	2	3	12	Monitor the condition of bearings and maintain them

			- Heavy load	- Stopping the aero plane						well lubricated
		- Wear on wheel teeth	- Heavy load - High rotation speed - Friction	- Worn belt - Air cooler can be shut down	Inspection	2	2	3	12	Inspect the condition of the wheels Check and stabilize the steering parameters operation
		- Sheared shaft	- Significant vibration	- Stopping the aero plane	VAHH - V2	2	3	1	6	Maintain detectors Perform periodic visual checks If necessary, dismantle and check
		- Fan does not turn or turns slowly	- Strained, worn or torn belt - Worn drive wheel	- Motor turns in a vacuum - Motor overload - Cooling fault	- Motor amperage - Bundle outlet oil temperature (TI913)	3	2	4	20	- Check the condition of the belts and their tension. - Check the gears - Use good quality belts

Section	BOG Propane		System	EBARA electric pump						
Circuit	Commercial propane		Subsystem	Electric motor		Tag Number				425/6101 D/E
Element	Function	Failure mode	Cause	Effect	Detection	Risk F	Risk G	Risk D	Risk C	Comments
Stator block	Chalk the rotating field	- Damage to insulation in windings	- Overload - Mechanical vibration - Premature ageing	- Short circuit - Overheating	SEPAM PT100 relay	1	3	1	3	Check and control connections. Monitoring operating parameters
		Short circuit	- Overheating (overload) - Bare conductor - Insulation fault between coils	- Engine stops - Compressor stop	SEPAM PT100 relay	1	3	1	3	
Rotor block	Ensures the rotation movement	Rotor-stator friction	- Bearing wear - Shaft misalignment - High levels of vibration	- Overheating - Insulation wear - Engine stop	SEPAM relay	1	3	1	3	Check the condition of the bearings, and monitor the intensity of the vibrations.
		Shaft twisting	- Blocking - Warm-up - Vibrations	- Vibration - Shear	Noise	1	3	3	9	Given the cross-section of the tree, the probability of these modes of default rates remain very low.
		Shaft bending	- Clumsy	- Vibration - Overheating	Noise	1	3	3	9	
Terminal box	Connection point	Overheating of terminals (calcination) Loss of seal	- Loose connections - Loose lid	- Loss of ATE protection - Water seepage	Visual inspection	1	2	4	8	If possible, provide a means of detection.
Motor body	Contain and protect the elements	- Cracking or breaking	- Corrosion - External shock	- Risk of water ingress - Risk of accidents for staff - Degradation of isolations in windings	Visual inspection	1	5	3	15	The environment is corrosive (close to the sea). Inspection remains essential, even if the probability of failure is low.
Bearings	Supporting and guiding the tree	- Wear and tear	- Ageing - Lubrication fault - Overload	- Warm-up - Vibration - Engine lock	Probes connected to the PC	2	2	3	12	Monitor the condition of bearings and keep them well lubricated

Flanges	Bearing housing	- Torn metal at the lodge - Cracking	- Lubrication fault - Overheating - Vibration	- Rotor lock - Rotor misalignment	Noise	1	2	3	6	Monitor the intensity of vibrations and lubrication conditions
Ventilation	Cooling	- Imbalance	- Bearing wear	- Poor cooling - Overheating	SEPAM relay	1	2	1	2	Check the condition of the bearings
		- Plugging of cooling	- Deposition of impurities		PT 100	2	2	1	4	Clean the cooling

Section	BOG Propane		System	EBARA motor pump						
Circuit	Commercial propane		Subsystem	Vertical centrifugal pump		Tag Number				425/6101 D/E
Element	Function	Failure mode	Cause	Effect	Detection	Risk				Comments
						F	G	D	C	
Pump body	Supporting the engine and pump	Degradation Cracking	- Corrosion - External mechanical shock	- Gas leak	Visual	1	2	3	6	Checking and visual inspection.
Hydraulic shaft	Ensures the rotation movement	Twist	- Blocking	- Vibration - Stopping the pump	Inspection	2	3	2	12	Inspect frequently and monitor operating parameters.
		Imbalance	- Clumsy - Flexion	- Stopping the pump	Inspection	3	3	3	24	
		Crack or break	- Vibration - Fatigue	- Stopping the pump	Inspection	1	3	3	9	
Tank	Carrying the fluid	Crack Degradation	- Corrosion	- Leak	/	1	3	4	12	Provide protection against corrosion
Impellers	Fluid suction and delivery	Crack	- Corrosion - Mechanical shock due to worn shaft bearings	- Imbalance - Stopping the pump	Inspection	1	3	3	9	Stop the pump and check the condition of the impeller
		Metal stripping	- Cavitation	- Imbalance - Stopping the pump	Inspection	2	3	3	18	The pump is protected against cavitation by a recirculation line Stop and check
Diffusers	Fluid orientation	Metal stripping	- Cavitation	- Disturbance flow	/	1	2	4	8	
Mechanical seal	Ensures water tightness	Leakage	- Wear and tear - Damaged seal - Poor lubrication and cooling - Vibration	- Gas leak - Risk of forming an ATEX atmosphere	- Pressure transmitter - Inspection	3	3	3	27	Check the condition and level of the methanol tank. Check condition and oil level. Check the condition of the seals

Roller bearings	Support and guide the pump's rotating parts	Wear and tear Overheating	- Poor lubrication - Ball degradation - Shaft unbalance - Misalignment	- Seizure - Blocking - Vibration	- Thermocouple - Inspection	3	2	1	6	Ensure proper lubrication of bearings and monitor their condition.
Methanol pot	Contain methanol for trim cooling	Loss of containment	- Corrosion - External mechanical shock	- Methanol leak - Poor lubrication	- Ice level (LG)	1	1	1	1	Inspect and check the condition of the walls and connections. Cleaning the pipes
		Clogged pipes	- Presence of impurities	- Warming up the methanol	- Transmitter for pressure	3	1	1	3	
Coupling	Connect the motor and pump. Compensates for travel	Imbalance	- Mechanical shock	- Vibration - Stopping the pump	/	2	2	4	16	Check coupling balance

Section	**BOG Propane**		**System**	**Air cooler**						
Circuit	**Propane refrigerant**		**Subsystem**	**/**		**Tag Number**				**405/6104**
Element	**Function**	**Failure mode**	**Cause**	**Effect**	**Detection**	**Risk** F	G	D	C	**Comments**
Electric motor	Fan drive	Damage to the engine	- Overload - Surge voltage - Cooling fault	- Stopping the aero plane	SEPAM PT100 relay	2	3	1	6	Check and control connections. Monitoring operating parameters
		Short circuit	- Overheating (overload) - Bare conductor - Insulation fault between coils	- Engine stops - Compressor stop	SEPAM PT100 relay	1	3	1	3	
		Rotor-stator friction	- Bearing wear - Shaft misalignment - High levels of vibration	- Overheating - Insulation wear - Engine stop	SEPAM relay	1	3	1	3	Check the condition of the bearings, and monitor intensity vibrations.
		- Cooling system shutdown	- Bearing wear - Damage to the blades	- Poor cooling - Overheating - Damage to the engine	SEPAM PT100 relay	1	3	1	3	Check the condition of the bearings. Check the condition of the blades.
Belts	Provides the link between the wheels (drive wheel/ aero wheel)	- Worn belt - Tensioned belt - Torn belt	- Ageing - Cutting wheel teeth - Incorrect belt tension - Misalignment	- Engine idling - Non-driven fan - Cooling fault	- Motor amperage - Gas outlet temperature - Noise	3	2	2	12	Check the condition of the belts and their tension. Check the sprockets Use good quality belts
Bearings	Supporting and guiding the shaft and blades	- Wear and tear	- Ageing - Lubrication fault - Overload	- Vibration - Imbalance	- Inspection - Noise	2	2	4	16	Monitor the condition of bearings and keep them well lubricated

Toothed wheels	Transmission and reception of rotation	- Tooth wear	- Heavy load - High rotation speed - Friction	- Worn belt - Air cooler can be shut down	Inspection	2	2	3	12	Inspect the condition of the wheels
Fan blades	Moving air	- Damage	- Vibration - External mechanical shock	- Vibration - Clumsy - Cooling fault	Noise Inspection	2	3	3	18	Carry out regular visual checks
Bundles	Carrying the fluid	Crack	- Pressure relief - Corrosion - External mechanical shock - Erosion	- Gas leak and formation of an atmosphere (ATEX)	- Inspection - Discharge pressure compressor	1	4	3	12	Monitor operating parameters.
		Damage and clogged fins	- External mechanical shock	- Decrease in air cooler efficiency	Visual	3	2	2	12	Cleaning the fins

III.3.3 Summary of the FMECA analysis

Following analysis using the FMECA method, we found that the level of criticality varies according to the nature of the components, their function, their place in the system and the detection systems and means installed.

The analysis shows that all the risks are located in the ALARP (as low as reasonably practicable) zone, meaning that these risks require measures whose financial impact is reasonable and coincides with the objectives targeted by the complex. On the other hand, failure to control these risks will have major effects on personnel, production facilities and the environment, resulting in considerable economic losses. The GL1K accident in Skikda is a case in point.

The analysis shows that a large number of detectors are used to detect the effect of the failure, and not the causes or the failure mode itself. This late detection results in the equipment generally being shut down. These unexpected stoppages lead to disruptions in the manufacturing process, and in some cases require urgent intervention.

III.3.4 General summary of risk analysis

The analyses carried out, whether using of FMECA method, show that the risks of operating parameter drift or equipment failure are omnipresent, and their effects will have repercussions on personnel, installations and the environment. This control will focus on reducing the probability of occurrence of the event, by implementing an inspection and maintenance plan, where the frequency and types of action will be relative to the sensitivity of the elements, and the severity of the risks.

In terms of preventing the risks associated with operating parameter deviations, particular attention must be paid to the control units and loops. Periodic inspections and controls must beprescribed, and a schedule must be drawn up and adhered to. Subsequently, depending on the observations made in situ, maintenance actions will be programmed.

With regard to problems associated with the operation of rotating machines, and based on tables below, failures are common in bearings, seals, couplings, etc. These failures can have serious effects on the wholemachine if they are not detected. These failures can have serious effects on the whole machine if they are not detected, by frequency of occurrence causing an accumulation of effects on othercomponents, or by the seriousness of the direct effects.

To this end, the company must draw up a sample inspection and maintenance schedule. This analysis and schedule are not exhaustive. Modifications, revisions and improvements will have to be made in order to optimize maintenance tasks, reduce costs and ensure the safety of people and installations.

Table.III.16- Frequency rating

Value	Failure frequency
1	Virtually non-existent failure on the plant or on similar plants in operation (once/10 years)
2	Failure rarely seen on the plant or on similar existing plants in operation (once/3 years)
3	Occasional failure of the plant or similar existing plant in operation (once a year)
4	Frequent failure of a known component, the installation or other components. similar existing plants in operation (once a month)

Table.III.17- Severity rating

Quotation		Evaluation criteria		
Value	**Level of gravity**	**Time IT intervention**	**Impact on equipment**	**Impact on safety**
1	Minor	Very short TI	Minor failure, equipment intact	/
2	Average	TI short	Medium failure, material quickly repairable	!
3	Important	Average TI	Major failure, repair long	!
4	Major	TI long	Serious failure, major material damage, the environment around the machine is reached	Accident that could jeopardize the safety of people
5	Catastrophic	TI very long	Destruction of the means of production replacement	Accident involving the safety of people

NB: The effect of failure is expressed in terms of downtime, product non-conformity and personal safety.

Table.III.18- Non-detection rating

Rating criteria		Evaluation criteria
1	Detection insured	The measures taken ensure total detection of the initial cause or mode of action. (e.g. automatic control)
2	Detection possible	The cause or mode of failure is detectable, but the risk of failure is not. (continuous monitoring by an operator)
3	Detection random	The cause or mode of failure is difficult to detect, or the failure elements are not available. detection are of little use
4	Not detectable	There is no way of detecting the failure before the effect occurs.

Criticality:

Criticality is obtained by multiplying the three previous criteria (F, G, D), so the valuesobtained are between 1 and 80, including :

Table.III.19- Criticality matrix

Frequency	**4**	16	32	48	64	80	**4**	**No detection**
	3	9	18	27	36	45	**3**	
	2	4	8	12	16	20	**2**	
	1	1	2	3	4	5	**1**	
		1	**2**	**3**	**4**	**5**		
		Gravity						

Table.III.20- Risk levels and acceptability criteria

Risk	Perception
Level 1	Negligible risk
Level 2	Tolerable risk (MMR risk control measures): Reduction of risk to as low as reasonably possible.
Level 3	Intolerable risk (the risk must be radically refused)

CHAPTER IV:

THE INNOVATION

IV.1 INTRODUCTION:

In the realm of Health, Safety, and Environmental (HSE) management, ensuring compliance and minimizing risks are paramount for the sustainability and safety of any industrial operation. Traditional methods of HSE management often involve manual data collection and analysis, which are not only time-consuming but also prone to human error. With the rapid advancement of Artificial Intelligence (AI) technologies, there is a significant opportunity to revolutionize the way HSE is implemented and monitored in industries. This thesis explores the integration of AI technologies into HSE management, aiming to enhance the efficiency, accuracy, and predictive capabilities of HSE systems.

The transition toward AI-enhanced HSE management systems can significantly reduce operational risks and improve compliance with environmental and safety regulations. AI technologies, such as machine learning algorithms and natural language processing, can analyze large volumes of data from various sources, including sensors, logs, and reports. By leveraging AI, companies can predict potential HSE incidents before they occur, enabling proactive rather than reactive management strategies.

This study will focus on developing an AI-based framework for HSE analysis, drawing from the initial development of an AI-Failure Mode, Effects, and Criticality Analysis (AI-FMECA) software site previously constructed. The AI-FMECA tool has demonstrated potential in identifying and addressing failure modes in industrial processes. Building on this foundation, the thesis will extend the application of AI to encompass broader HSE analytical functions, thereby creating a comprehensive AI-HSE Office Study.

The objectives of the thesis are to:

1. Evaluate the current landscape of AI applications in HSE management.
2. Develop an AI-enhanced tool that can perform comprehensive HSE analyses, including risk assessment, incident prediction, and compliance tracking.
3. Conduct a case study to validate the effectiveness of the AI-enhanced HSE tool in a real-world industrial setting.
4. Analyze the potential barriers to the adoption of AI in HSE and propose solutions to mitigate these challenges.

IV.2 The project idea (the proposed solution) :

The project entails creating an innovative AI-based software site solution for industrial risk management, in brief AI-HSE Engineering analysis Office with a particular emphasis on the AMDEC (Analysis of Failure Modes, Effects, and Criticism) approach. By using artificial intelligence to streamline risk identification, mitigation processes, predictive analytics, and prioritization, It also offers advanced data visualization for a clear representation of analysis results and comprehensive reporting capabilities, this program seeks to transform the AMDEC analysis process. A straightforward data entry interface with natural language processing capabilities would be helpful to users. The machine learning algorithms built into the program will learn and adapt over time, offering smart insights, automating repetitive processes, and recommending the best mitigation techniques. Shrewd reporting features will provide a thorough and aesthetically pleasing summary of important concerns. Scalability, adaptability, and data security are the main priorities of this AI-driven software, which aims to offer an advanced platform for industry.

The project proposes the development of an innovative AI-based software solution tailored for industrial risk management, specifically focusing on the AMDEC (Analysis of Failure Modes, Effects, and Criticism) methodology. This advanced software aims to revolutionize the AMDEC analysis process by leveraging artificial intelligence to enhance risk identification, streamline mitigation processes, and provide predictive analytics. The solution will incorporate sophisticated data visualization tools to present analysis results clearly and offer comprehensive reporting capabilities.

The software will feature a user-friendly data entry interface equipped with natural language processing (NLP) capabilities, making it accessible and efficient for users. The integration of machine learning algorithms will enable the software to learn and adapt over time, providing smart insights, automating repetitive tasks, and recommending optimal mitigation techniques. Enhanced reporting features will deliver detailed and visually appealing summaries of critical issues, facilitating better decision-making.

Prioritizing scalability, adaptability, and data security, this AI-driven platform aims to set a new standard in industrial risk management. By offering a robust and versatile solution, the project seeks to empower industries with the tools needed to conduct thorough AMDEC analyses, ultimately leading to improved safety, efficiency, and operational.

IV.2 The suggested values

Creating an innovative AI-based software solution for industrial risk management with a focus on the AMDEC (Analysis of Failure Modes, Effects, and Criticism) approach is a promising idea. Here's a consolidated view of the suggested values and considerations for your project based on recent insights from various sources:

IV.2.2 Enhanced Risk Identification and Mitigation:

- AI can significantly improve the accuracy and efficiency of risk identification and mitigation processes by analyzing large datasets to detect patterns and anomalies. This helps in real-time risk detection and proactive mitigation, reducing potential downtime and financial losses

IV.2.3 Predictive Analytics and Machine Learning:

- Incorporating machine learning algorithms allows the system to learn from historical data and improve its predictions over time. Predictive analytics can foresee potential risks before they materialize, enabling preemptive action and resource optimization (

IV.2.4 Data Visualization and Reporting:

- Advanced data visualization tools are essential for presenting analysis results clearly and comprehensively. Effective visualization helps in understanding complex data and making informed decisions. AI can also automate the generation of detailed reports, ensuring that they are both informative and aesthetically pleasing

IV.2.5 Natural Language Processing (NLP):

- An intuitive data entry interface using NLP can make the system user-friendly, allowing users to interact with the software in natural language. This simplifies the data entry process and enhances user engagement

IV.2.6 Continuous Learning and Adaptation:

- The system should continuously learn from new data, refining its risk assessments and recommendations. This adaptive learning ensures that the software remains relevant and accurate over time, even as the risk landscape evolves (ProjectAI).

IV.2.7 Scalability and Adaptability:

- The software should be scalable to accommodate growing data volumes and adaptable to different industrial contexts. This flexibility is crucial for maintaining performance and relevance in diverse environments

IV.2.8 Data Security and Privacy:

- Ensuring robust data security measures is critical to protect sensitive information. Implementing security protocols and maintaining compliance with relevant regulations will help build trust and reliability in the system

IV.2.9 Integration and Collaboration:

- Integrating the AI system with existing IT infrastructure and fostering collaboration among stakeholders are vital for a seamless risk management process. Effective communication and real-time information sharing can enhance overall risk management capabilities

By focusing on these values, your AI-driven software can provide a comprehensive, efficient, and user-friendly platform for industrial risk management, transforming the AMDEC analysis process and contributing to safer and more resilient industrial operations.

IV.3 Team

The development of this groundbreaking platform, which seamlessly blends Health, Safety, and Environment (HSE) analyses with advanced Artificial Intelligence (AI) technologies, is the result of a collaborative effort by a dedicated team of experts. Leading this initiative are Mohammed Salah Edine Lazoueche, Bilal Benboudissa, Betaher Mohammed, and Aymen kourichi. Each member brings a unique set of skills and expertise to the table, ensuring a comprehensive and innovative approach to the project.

Mohammed Salah Edine, with his background in project management and HSE practices, has been instrumental in overseeing the strategic direction of the project. His deep understanding of the challenges faced in traditional HSE analyses has been pivotal in shaping the vision for the AI-integrated platform. Bentaher Mohammed,Aymenkourichi , a specialists in AI and machine learning, has spearheaded the technical development, ensuring that the platform leverages the latest in AI technologies to enhance risk assessment capabilities.

Bilal Ben Boudissa with his expertise in data analytics and risk management, has played a crucial role in refining the data processing techniques and predictive modeling features of the platform. Mohammed Salah Edine Lazoueche, on the other hand, has focused on the user interface and experience design, ensuring that the platform is not only powerful but also accessible and intuitive for HSE professionals.

Together, this team has worked tirelessly to bridge the gap between HSE practices and AI, creating a tool that promises to redefine risk management in various industries. Their collaborative spirit and commitment to innovation have been the driving forces behind the development of this transformative platform, setting a new benchmark for HSE excellence.

IV.4 Project Objectives

The primary objective of integrating Artificial Intelligence (AI) with Health, Safety, and Environment (HSE) analyses, specifically Failure Mode, Effects, and Criticality Analysis (FMECA) and Hazard and Operability Study (HAZOP), is to revolutionize the way risks are identified, assessed, and mitigated in industrial settings. This project aims to develop a web-based platform that leverages AI to enhance the efficiency, accuracy, and comprehensiveness of HSE analyses. The following are the key objectives guiding the development and implementation of this platform:

IV.4.1 Enhance Risk Identification and Assessment

- Improve Accuracy: Utilize AI algorithms to analyze complex data sets, identify patterns, and detect potential hazards with greater accuracy than traditional methods.
- Increase Coverage: Ensure a more comprehensive analysis by considering a broader range of variables and scenarios that might be overlooked by human analysts.
- Real-time Monitoring: Implement AI systems capable of real-time data processing to provide immediate alerts and insights, enabling proactive risk management.

IV.4.2 Streamline the Analysis Process

- Automate Routine Tasks: Develop AI tools to automate data collection, entry, and preliminary analysis tasks, reducing the workload on HSE professionals.
- User-Friendly Interface: Design an intuitive platform that simplifies the HSE analysis process, making it accessible to users with varying levels of technical expertise.
- Integrate with Existing Systems: Ensure seamless integration with current HSE management systems and databases, minimizing disruption to existing workflows.

IV.4.2 Foster a Culture of Continuous Improvement

- Predictive Analytics: Employ AI to forecast potential risks and hazards, allowing for preventive measures to be taken before incidents occur.
- Learning from Incidents: Use machine learning algorithms to analyze past incidents and near-misses, identifying trends and contributing factors to inform future risk assessments.
- Promote Proactive Safety: Encourage a shift from reactive to proactive safety measures by providing actionable insights and recommendations based on AI analysis.

IV.4.3 Ensure Compliance and Best Practices

- Regulatory Compliance: Develop the platform to align with industry standards and regulatory requirements, ensuring that all analyses meet or exceed legal and best practice benchmarks.
- Knowledge Sharing: Create a repository of AI-generated insights and analyses that can be shared across the organization or industry to promote learning and continuous improvement.
- Audit Trails: Implement robust audit trail features that track changes, decisions, and actions taken as a result of the AI-assisted analyses, supporting accountability and transparency.

IV.4.4 Drive Cost and Time Efficiency

- Reduce Analysis Time: By automating and streamlining the analysis process, aim to significantly reduce the time required for conducting FMECA and HAZOP studies.
- Cost Savings: Achieve cost savings through the prevention of incidents, reduced need for manual analysis, and the optimization of resources based on AI-driven insights.

IV.4.5 Promote Sustainability and Environmental Protection

- Environmental Impact Assessment: Integrate tools for assessing the environmental impact of potential hazards, contributing to sustainable operations and compliance with environmental regulations.

- Resource Optimization: Use AI to optimize the use of resources, minimizing waste and environmental footprint.
- By achieving these objectives, the AI-integrated HSE analysis platform will not only enhance safety and risk management practices but also contribute to operational efficiency, regulatory compliance, and environmental sustainability, setting a new standard for HSE excellence in the industry.

IV.5 Project Implementation Schedule

The implementation of the AI-integrated HSE analysis platform is a multi-phased project that requires careful planning and execution. The following schedule outlines the key stages and estimated timelines for the project's completion. This schedule is subject to adjustments based on project progress, resource availability, and any unforeseen challenges.

IV.5.1 Phase 1: Project Planning and Preparation (1-2 Months)

- Week 1-2: Project Kickoff and Team Assembly
  - Finalize project scope and objectives.
  - Assemble project team and assign roles and responsibilities.
- Week 3-4: Requirements Gathering and Analysis
  - Engage with stakeholders to gather detailed requirements.
  - Analyze existing HSE processes and identify integration points for AI.
- Week 5-6: Technology and Vendor Selection
  - Evaluate and select AI technologies and tools.
  - Identify and partner with technology vendors and service providers.
- Week 7-8: Development and Implementation Planning
  - Develop a detailed project plan, including milestones and deliverables.
  - Establish a communication plan and project governance structure.

IV.5.2 Phase 2: Platform Development (4-6 Months)

- Month 1-2: System Design and Prototyping
  - Design the platform architecture and user interface.
  - Develop a prototype for demonstration and feedback.
- Month 3-4: Core Functionality Development
  - Implement AI algorithms for data analysis and risk prediction.
  - Develop data processing and integration modules.
- Month 5-6: Testing and Iteration
  - Conduct thorough testing, including unit tests, integration tests, and user acceptance testing.

- Iterate based on feedback to refine platform functionality and user experience.

IV.5.3 Phase 3: Training, Documentation, and Support (1 Month)

- Week 1-2: User Training
  - Conduct comprehensive training sessions for end-users.
  - Develop training materials and resources for future reference.
- Week 3-4: Documentation and Knowledge Transfer
  - Finalize user manuals, system documentation, and support materials.
  - Ensure knowledge transfer to internal IT and HSE teams for ongoing support.

IV.5.4 Phase 4: Deployment and Integration (2-3 Months)

- Month 1: Pilot Deployment
  - Deploy the platform in a controlled environment for pilot testing.
  - Collect data on platform performance and user interaction.

- Month 2-3: Full Deployment and Integration
  - Roll out the platform across the organization.
  - Integrate with existing HSE management systems and databases.

IV.5.4 Phase 5: Post-Deployment Monitoring and Evaluation (Ongoing)

- Month 1-3: Monitoring and Feedback Collection
  - Monitor platform usage and performance.
  - Collect user feedback for continuous improvement.

- Month 4-6: Evaluation and Iteration
  - Evaluate the impact of the platform on HSE processes and outcomes.
  - Plan and implement updates or enhancements based on evaluation findings.

IV.5.5 Phase 6: Maintenance and Scaling (Ongoing)

- Ongoing: Maintenance and Support
  - Provide regular maintenance and technical support.
  - Scale the platform as needed to accommodate growing data volumes and user demands with HAZOP and another analysis ai-tools.

This schedule is designed to ensure a methodical and thorough implementation process, with each phase building upon the successes of the previous one. Regular check-ins and adjustments will be made to ensure the project stays on track and meets its objectives within the planned timeframe.

IV.6 The nature of innovation

The integration of Artificial Intelligence (AI) with Health, Safety, and Environment (HSE) analyses, specifically Failure Mode, Effects, and Criticality Analysis (FMECA) and Hazard and Operability Study (HAZOP), represents a significant innovation in the field of risk management and industrial safety. This innovation is multifaceted, encompassing technological advancements, process improvements, and strategic enhancements to traditional HSE practices. The nature of these innovations can be explored across several dimensions:

IV.6.1 Technological Integration

- AI-generated insights for Risk Prediction: The use of Ai and predictive analytics to forecast potential risks and hazards represents a leap forward in proactive safety management. By analyzing historical data and identifying patterns, AI can predict and alert stakeholders to potential issues before they occur.
- Real-time Data Processing: The ability of AI systems to process and analyze data in real time allows for immediate identification of hazards and risks, enabling swift corrective actions and reducing the window for potential incidents.
- Automation of Analytical Tasks: AI automates many of the routine and time-consuming tasks associated with FMECA and HAZOP studies, such as data collection, entry, and preliminary analysis, freeing up HSE professionals to focus on higher-value tasks.

IV.6.2 Process Enhancements

- Streamlined Analysis Workflows: The integration of AI simplifies and accelerates the HSE analysis process, making it more accessible to a broader range of users and reducing the time required for comprehensive risk assessments.
- Enhanced Accuracy and Coverage: AI's ability to consider a vast array of variables and scenarios ensures a more thorough analysis, identifying risks that might be overlooked by traditional methods.
- Continuous Learning and Improvement: The platform can learn from each analysis, continuously improving its algorithms and recommendations based on new data and outcomes, fostering a culture of continuous improvement in HSE practices.

IV6.2 Strategic Innovations

- Proactive Risk Management: Shifting the focus from reactive to proactive safety measures, the AI-integrated platform enables organizations to anticipate and mitigate risks before they materialize, enhancing overall safety and reducing the potential for incidents.
- Resource Optimization: By prioritizing risks and recommending targeted interventions, the platform helps optimize the allocation of resources, ensuring that efforts and investments in HSE are strategic and cost-effective.
- Sustainability and Compliance: The platform's ability to assess environmental impacts and ensure regulatory compliance supports organizations in achieving their sustainability goals and maintaining a strong corporate social responsibility profile.

IV.6.3 User Experience and Accessibility

- Intuitive Interface Design: The platform is designed with user-friendliness in mind, featuring an intuitive interface that makes advanced AI capabilities accessible to HSE professionals without extensive technical expertise.

- Customizable and Scalable: The platform can be customized to meet the specific needs of different industries and organizations, and it is scalable to accommodate growing data volumes and user demands.

In summary, the innovation embodied in the AI-integrated HSE analysis platform is transformative, offering a new paradigm for risk management that is more efficient, accurate, and strategic than traditional approaches. By leveraging the power of AI, this platform not only enhances safety and environmental protection but also contributes to operational efficiency and competitive advantage for organizations across various sectors.

IV.7 Areas of innovation.

When exploring the transformative impact of Artificial Intelligence (AI) on Health, Safety, and Environment (HSE) analyses, particularly in methods like Failure Mode, Effects, and Criticality Analysis (FMECA) and Hazard and Operability Study (HAZOP), it's essential to categorize the innovations into distinct areas. Each area underscores a unique facet of how AI is revolutionizing HSE, from enhancing technological capabilities to improving operational efficiencies and fostering strategic advancements. Here's a structured overview of these areas:

IV.7.1 Health, Safety, and Environmental Security

- Focus on High-Risk Sectors: Highlight the specific applications of AI in high-risk industries, such as oil and gas, where HSE considerations are paramount.
- Universal Application: Emphasize that while AI innovations are tailored to high-risk sectors, their benefits and applications are relevant across all industries prioritizing HSE.

IV.7.2. Technological Breakthroughs

- Integration of AI insights and HSE analyses: Delve into how AI and machine learning are being woven into HSE analyses, boosting predictive accuracy, pattern detection, and data handling.
- Leveraging inputs and Humen Data: Examine the pivotal role of inputs and Humen-think in supplying real-time data for AI-driven HSE analyses, enhancing the timeliness and precision of insights.

IV.7.3 Operational Improvements

- Streamlining with Automation: Detail how AI is automating routine HSE tasks, from data gathering to analysis, thereby boosting efficiency and allowing professionals to concentrate on more critical tasks.
- Optimizing Resources: Discuss how AI aids in the strategic allocation of resources by identifying priority risks and suggesting targeted actions, thereby enhancing the cost-effectiveness of HSE operations.
- AI-Driven Decision Support: Showcase the development of AI-powered decision support tools that offer data-backed recommendations for HSE planning and risk mitigation.

IV.7.4 Strategic Evolution

- Anticipating Risks: Explain how AI propels HSE from reactive to proactive by forecasting potential hazards, thereby enhancing safety and reducing incidents.
- Sustainability and Compliance: Describe how AI integrates environmental impact assessments and regulatory compliance checks into HSE analyses, supporting sustainability objectives and minimizing legal and financial risks.
- Iterative Enhancement: Outline how AI enables ongoing refinement of HSE practices by analyzing outcomes and dynamically adjusting algorithms and suggestions.

IV.7.5 Regulatory Adherence and Reporting

- Automated Compliance: Describe how AI simplifies compliance by automatically monitoring operations against regulatory standards, reducing the risk of non-compliance penalties.

- Enhanced Documentation: Discuss the improvements in HSE reporting and record-keeping made possible by AI, including the automatic generation of reports and maintenance of comprehensive audit trails.

IV.7.6 Education and Knowledge Exchange

- Advanced Training Programs: Explore how AI is revolutionizing HSE training, offering simulations, predictive scenarios, and personalized learning experiences hence using it in lessons and lectures.
- Shared Knowledge Platforms: Discuss how AI facilitates the sharing of HSE knowledge and best practices, including the creation of databases with AI-generated insights.

By compartmentalizing the innovations into these sections, we gain a thorough understanding of how AI is reshaping HSE analyses. Each section illuminates specific AI applications that are driving progress in HSE, from technological marvels to strategic advancements, ultimately enhancing safety, efficiency, and environmental stewardship.

IV.8 Strategic Market Analysis

IV.8.1 The Market Segment

The market segment for an AI-integrated Health, Safety, and Environment (HSE) analysis platform is both new and broad, catering to a wide range of industries that prioritize risk management, safety, and environmental compliance. Key segments include:
- Oil and Gas: This industry is characterized by high-risk operations and a strong emphasis on HSE due to the potential for significant environmental impact and safety concerns.
- Manufacturing: Across various manufacturing sectors, from automotive to pharmaceuticals, there is a growing need for advanced HSE solutions to ensure worker safety and regulatory compliance

.- Chemicals and Petrochemicals: Companies in this sector face complex HSE challenges related to hazardous materials and processes, making AI-driven solutions particularly appealing.- Construction: With its dynamic and often unpredictable work environments, the construction industry is increasingly looking for innovative HSE tools to mitigate risks.

- Energy and Utilities: As this sector evolves towards renewable energy sources and smart grid technologies, HSE considerations remain paramount, necessitating advanced analytical tools.

IV.8.2 Measuring the Intensity of Competition

The intensity of competition in the market for AI-integrated HSE platforms can be assessed through several key indicators:
- Number of Competitors: The Absence of a single vendors offering similar solutions indicates a Fertile market. but It's important to analyze the indirect competitors (providers of traditional HSE software or consulting services that may integrate AI in the future) like sundaybizsys .

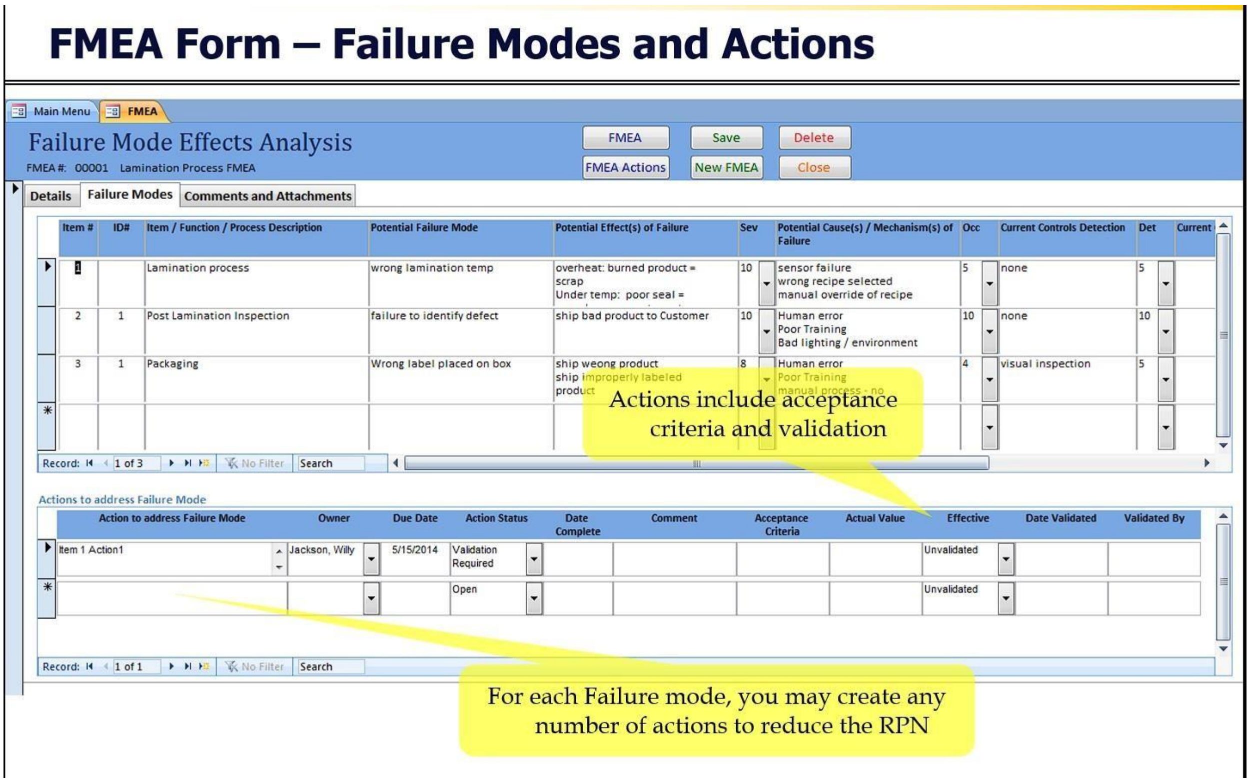


Figure.IV.1 - From "FMEA Form – Failure Modes and Actions," Sunday Business Systems, captured on June 5, 2024

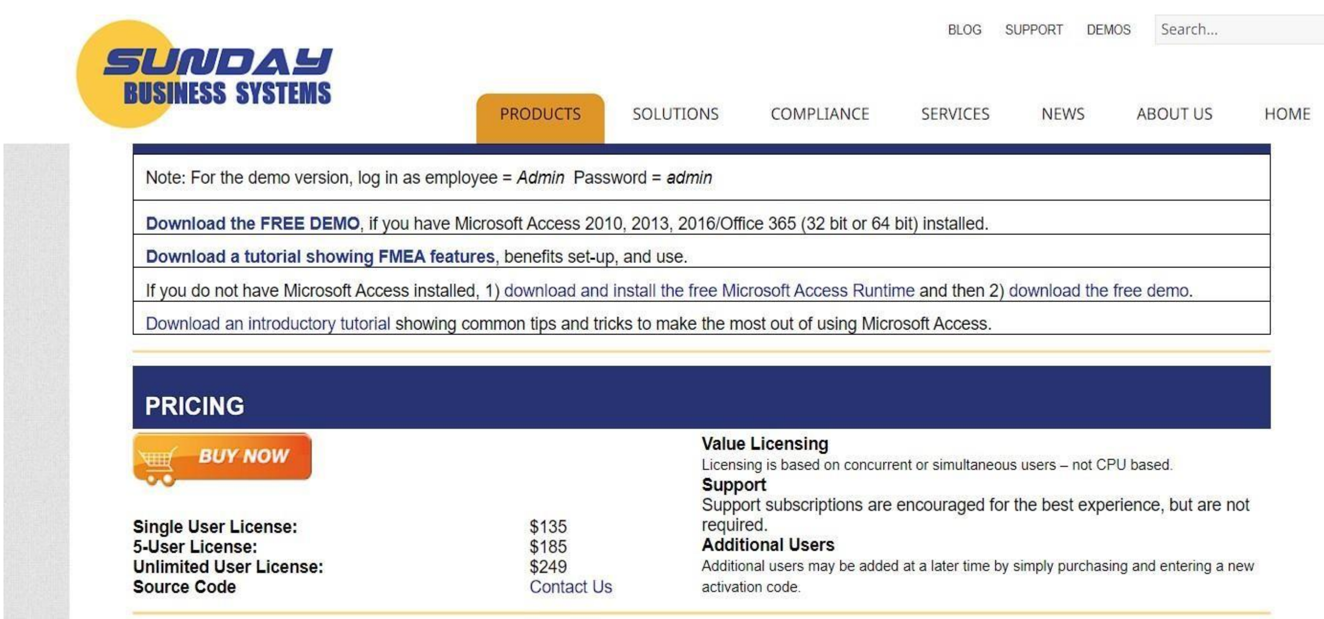


Figure IV.2-From "Sunday Business Systems Pricing Information," Sunday Business Systems, retrieved from a website screenshot on June 5, 2022

- Barriers to Entry: High barriers to entry, such as significant capital requirements, specialized technical expertise, or strong customer loyalty to existing solutions, can limit competition. Conversely, low barriers may lead to a more crowded and competitive market.
- Market Growth: A rapidly growing market can accommodate multiple players and may reduce the intensity of competition as everyone benefits from expanding demand. In contrast, a stagnant or declining market may intensify competition as companies vie for a shrinking customer base.
- Product Differentiation: The level of differentiation between offerings can affect competition. Unique features, superior technology, or strong brand reputation can provide a competitive advantage and reduce the intensity of competition for a particular

IV.8.3 Marketing Strategy

A successful marketing strategy for an AI-integrated HSE platform should focus on the unique value proposition it offers to the target market segments. Key elements of the strategy include:

- Emphasize Unique Selling Points: Highlight the platform's AI capabilities, such as predictive analytics, real-time monitoring, and automated risk assessments, which differentiate it from traditional HSE solutions.
- Demonstrate ROI: Showcase case studies and testimonials that demonstrate the tangible benefits of the platform, such as cost savings, improved safety records, and enhanced regulatory compliance
- Digital Marketing Campaign

Objective: Utilize digital marketing channels to reach and engage our target audience effectively.

- Build a High-Quality Website:

Ensure the website is SEO-optimized for relevant keywords.

Include detailed information about the platform, case studies, testimonials, and a blog.

- Content Marketing:

Create whitepapers, eBooks, blog posts, and videos.

Focus on topics like HSE best practices and the benefits of AI-driven solutions.

- Social Media Marketing:

Maintain active profiles on LinkedIn, Twitter, and Facebook.

Share content, engage with followers, and participate in industry discussions.

- Email Marketing:

Develop targeted email campaigns to nurture leads.

Send regular newsletters with updates, industry news, and insights.

- Paid Advertising Campaign:

Budget: Allocate $600 for a three-month campaign.
Platforms: Google Ads, LinkedIn Ads, Facebook Ads.
Objectives: Drive traffic to the website, generate leads, and increase brand awareness.
Metrics: Track impressions, click-through rates (CTR), conversion rates, and cost per lead (CPL)..

- Targeted Outreach: Develop marketing campaigns tailored to specific industry segments, addressing their unique HSE challenges and regulatory requirements.
- Educational Content: Provide valuable content, such as webinars, and blog posts, that educates potential customers about the benefits of AI in HSE and positions the company as a thought leader in the field.

- Partnerships and Alliances
Objective: Establish strategic partnerships to enhance our market reach and credibility.
Partner with Industry Associations:
Join HSE Industry associations.
Participate in industry events, conferences, and seminars-
Collaborate with Technology Partners:
form alliances With LOT device manufacturers and Al solution vendors.
Enhance the platform 's capabilities and market appeal.
Alliances with Consulting Firms:
- Partner with traditional HSE consulting firms Offer a hybrid solution combining AI insights with expert consulting.- Customer Support and Training: Offer comprehensive support and training programs to ensure customers can effectively use the platform and realize its full benefits. By focusing on these strategic elements, the marketing strategy can effectively communicate the platform's value, differentiate it from competitors, and drive adoption across the target market segments.

IV.8.4 : Economic Benefits of Implementing AI-FMECA

The integration of AI-FMECA process not only enhances operational efficiency and reliability but also provides significant economic benefits. This chapter delves into the financial advantages realized through this implementation, highlighting cost savings, increased productivity, and overall return on investment (ROI).

IV.8.5 Pricing Model and Revenue Projection

IV.8.5.1 Initial Pricing Model

Subscription Fee: $50 per month per company

8.5.2 Revenue Projections Based on 100 Companies

Monthly Revenue

100 companies * $50 = $5,000

Annual Revenue

$5,000 * 12 = $60,000

8.5.2 Cost of Implementation and Operation

Initial Development Costs: $8,000 (one-time)
Operational Costs: $1,000 per year
Profit Calculation (First Year)
Total Revenue
Annual Revenue: $60,000
Total Costs
Initial Development Cost: $8,000
Operational Costs: $1,000
Total Costs: $8,000 + $1,000 = $9,000
Profit/Loss

Profit: Total Revenue - Total Costs = $60,000 - $9,000 = $51,000

8.5.3 Economic Benefits for the Companies

8.5.4 Cost Savings

Reduced Maintenance Costs: Assuming a company spends $100,000 annually on maintenance, and AI-FMECA reduces this by 20%, each company saves $20,000 annually. For 100 companies, this totals $2,000,000 in savings.

8.5.5 Reduced Downtime

Increased Production: If each company can reduce downtime by 0.5%, and they generate $1 million in revenue annually, this increases revenue by $5,000 per company. For 100 companies, this totals $500,000 in additional revenue.

8.5.6 Extended Equipment Lifespan

Capital Expenditure Savings: If AI-FMECA extends the lifespan of critical equipment by 5 years, deferring $1 million in capital expenses, the annualized savings are $1,000 per company. For 100 companies, this totals $100,000 in deferred capital expenses.

8.5.7 Improved Safety and Risk Management

Cost Avoidance: Reducing accidents and associated costs. If accident-related costs are $100,000 annually per company, and AI-FMECA reduces these by 5%, each company saves $5,000. For 100 companies, this totals $500,000.

Summary of Economic Benefits for Companies

Total Cost Savings

Maintenance: $2,000,000

Increased Production: $500,000

Deferred Capital Expenditure: $100,000

Accident Cost Avoidance: $500,000

Total Savings and Additional Revenue: $2,000,000 + $500,000 + $100,000 + $500,000 = $3,100,000

Overall Economic Impact

With the revised accident cost savings, the financial outlook is as follows:

First-Year Profit for Service Provider: $51,000

Total Economic Benefit for Companies: $3,100,000

Long-Term Financial Outlook

As adoption increases beyond the initial 100 companies, the service provider will continue to see increased profits, and the economic benefits for the companies will also grow. Here’s how scaling might affect finances:

Year 2 and beyond

Increased Adoption: As the benefits become evident, more companies are likely to subscribe.

Reduced Costs: Operational efficiencies and economies of scale can reduce per-user costs.

IV.8.6 Experimental prototype

Two elements as instance

	Element	Function	Failure Mode	Effects	Causes	Detection	Severity	Occurrence	RPN	Recommendations
0	pipe	Transporting fluids within the refinery	Pipe corrosion	Fluid leakage, potential environmental contamination	Exposure to corrosive substances, lack of maintenance	2	2	1	4	Implement regular inspections, use corrosion-resistant materials
1	Tank	Storage of oil and gas	Tank rupture	Oil and gas spillage, Fire hazard	Corrosion, Overpressure, External impact	3	2	1	6	Regular inspection for corrosion, Pressure relief valve installation,

Figure.IV.3-From "the software site," FMEAC TOOL, retrieved from a website screenshot on June 5, 2024.

four elements as instance

	Element	Function	Failure Mode	Effects	Causes	Detection	Severity	Occurrence	RPN	Recommendations
0	Oil pump	Delivering lubricant under pressure	Failure to deliver lubricant	Machinery breakdown, Increased friction and wear on moving parts	Clogged filter, Pump motor failure, Lack of lubricant	2	2	1	4	Regular maintenance of filters, Monitoring lubricant levels, Trainir
1	Oil filter	Filtering out impurities from the oil	Clogging of the filter	Reduced oil flow, Increased risk of engine damage	Build-up of dirt and debris, Low-quality filter materia	3	2	1	6	Regular filter replacement, Use high-quality filter material
2	Oil drain p	Collecting and draining excess oil fro	Leakage of oil	Environmental contamination, Equipment damage	Corrosion, Faulty seals	3	1	2	6	Regular inspection of seals, Implement corrosion prevention mea
3	Gas air coc	Cooling the gas before it is released	Decreased cooling efficienc	Overheating of the gas, Reduced system efficiency	Clogged filters, Low refrigerant levels	3	1	2	6	Regular filter maintenance, Monitoring refrigerant levels and pres
4	Oil cooler	Cooling the oil to maintain optimal o	Loss of cooling capacity	Overheating of the oil, Reduced lubrication efficiency	Clogging of cooling fins, Loss of coolant, Mechanical	3	2	2	12	Regular cleaning and maintenance of cooling fins, Monitoring coo

Figure.IV.4-From "the software site," FMEAC TOOL, retrieved from a website screenshot on June 5, 2024.

IV.8.7 The interface

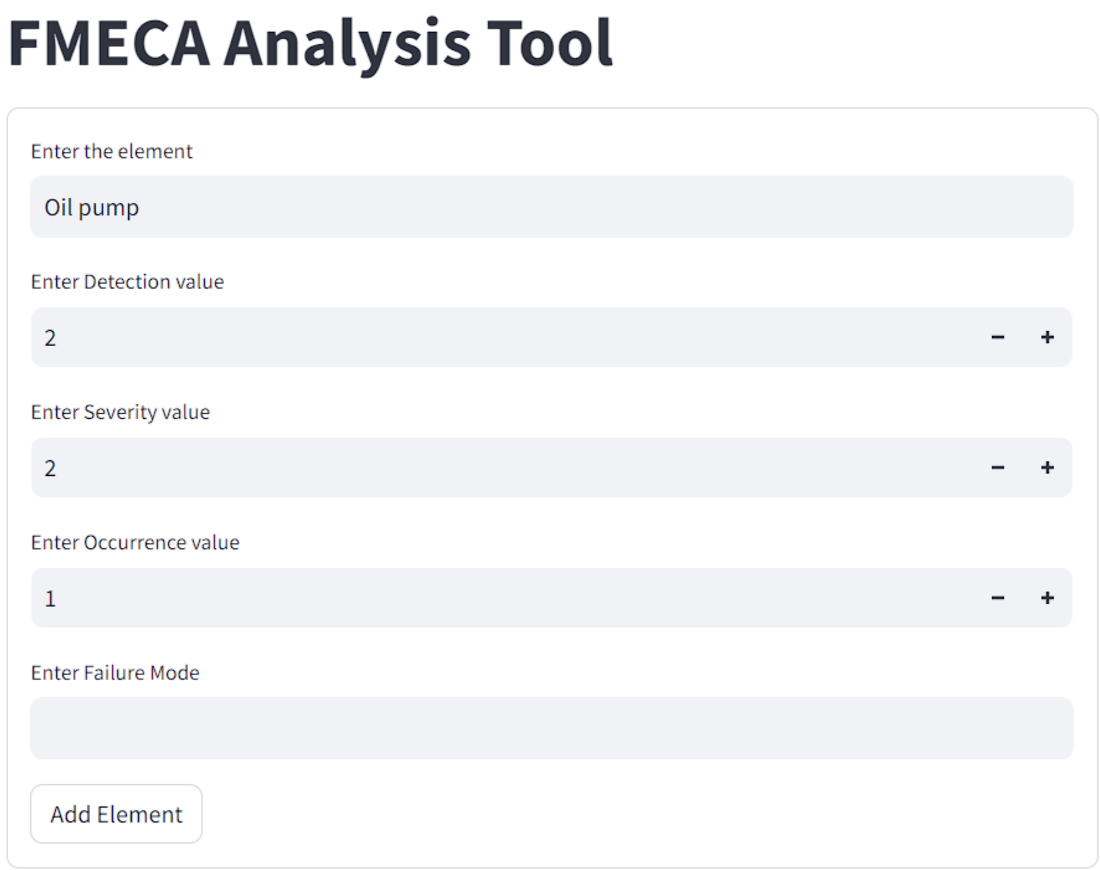


Figure.IV.5-From "the software site," FMEAC TOOL,
retrieved from a website screenshot on June 5, 2024.

IV.8.8 Conclusion

In conclusion, the innovative idea of integrating Artificial Intelligence (AI) with Health, Safety, and Environment (HSE) analyses, specifically through methods such as Failure Mode, Effects, and Criticality Analysis (FMECA) and Hazard and Operability Study (HAZOP), represents a groundbreaking advancement in risk management and industrial safety. This idea leverages the power of AI to enhance predictive capabilities, automate routine tasks, and provide actionable insights, marking a significant departure from traditional, manual HSE practices.

The blend of AI with HSE analyses not only improves the accuracy and efficiency of risk assessments but also enables a proactive approach to safety and environmental management. By predicting potential hazards and optimizing resource allocation, this idea supports a shift from reactive to proactive strategies, contributing to a safer and more sustainable industrial environment.

Moreover, the application of AI in HSE analyses opens up new avenues for continuous learning and improvement, as algorithms can be refined over time based on real-world data and outcomes. This iterative enhancement ensures that HSE practices remain effective and adaptable in the face of evolving industrial challenges and regulatory requirements.

By conducting this research, the thesis aims to contribute to the field of HSE management by showcasing how AI can be a transformative tool in enhancing the effectiveness and efficiency of safety and environmental compliance strategies. The outcome of this study could serve as a benchmark for future implementations of AI in HSE across various industries, potentially setting a new standard for how safety and environmental risks are managed in an increasingly complex and regulated world.

The integration of AI into HSE practices promises not only to enhance operational efficiencies but also to bolster the overall safety culture. This thesis will provide valuable insights into the practical implications of AI in HSE, offering a clear path forward for its adoption in enhancing safety and environmental stewardship.

In summary, the idea is transformative, offering a new paradigm for risk management that is more efficient, accurate, and strategic than traditional approaches. By harnessing the capabilitiesof AI, this innovation not only enhances safety and environmental protection but also contributesto operational efficiency and competitive advantage for organizations across various sectors. As industries continue to prioritize safety, sustainability, and compliance, the integration of AI with HSE analyses stands as a pivotal step forward in achieving these goals.

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